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Is socioeconomic position early in life associated with physical activity during adulthood following the accumulation of risk model with additive effects?

par

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RÉSUMÉ

L'activité physique améliore la santé, mais seulement 4.8% des Canadiens atteignent le niveau recommandé. La position socio-économique est un des déterminants de l'activité physique les plus importants. Elle est associée à l’activité physique de manière transversale à l’adolescence et à l’âge adulte. Cette thèse a tenté de déterminer s'il y a une association à long terme entre la position socio-économique au début du parcours de vie et l’activité physique à l’âge adulte. S'il y en avait une, un deuxième objectif était de déterminer quel modèle théorique en épidémiologie des parcours de vie décrivait le mieux sa forme.

Cette thèse comprend trois articles: une recension systématique et deux recherches originales. Dans la recension systématique, des recherches ont été faites dans Medline et EMBASE pour trouver les études ayant mesuré la position socio-économique avant l'âge de 18 ans et l'activité physique à ≥18 ans. Dans les deux recherches originales, la modélisation par équations structurelles a été utilisée pour comparer trois modèles alternatifs en épidémiologie des parcours de vie: le modèle d’accumulation de risque avec effets additifs, le modèle d’accumulation de risque avec effet déclenché et le modèle de période critique. Ces modèles ont été comparés dans deux cohortes prospectives représentatives à l'échelle nationale: la *1970 British birth cohort* (n=16,571; première recherche) et l’Enquête longitudinale nationale sur les enfants et les jeunes (n=16,903; deuxième recherche).

Dans la recension systématique, 10 619 articles ont été passés en revue par deux chercheurs indépendants et 42 ont été retenus. Pour le résultat «activité physique» (tous types et mesures confondus), une association significative avec la position socio-économique durant l'enfance fut trouvée dans 26/42 études (61,9%). Quand seulement l'activité physique durant les loisirs a été considérée, une association significative fut trouvée dans 21/31 études (67,7%). Dans un sous-échantillon de 21 études ayant une méthodologie plus forte, les proportions d'études ayant trouvé une association furent plus hautes : 15/21 (71,4%) pour tous les types et toutes les mesures d'activité physique et 12/15 (80%) pour l'activité physique de loisir seulement. Dans notre première recherche originale sur les données de la *British birth cohort*, pour la classe sociale, nous avons trouvé que le modèle d'accumulation de risque avec effets additifs s'est ajusté le mieux chez les hommes et les femmes pour l'activité physique de loisir, au travail et durant les transports. Dans notre deuxième recherche originale sur les données canadiennes sur l'activité physique de loisir, nous avons trouvé que chez les hommes, le modèle de période critique s'est ajusté le mieux aux données pour le niveau d'éducation et le revenu, alors que chez les femmes, le modèle d'accumulation de risque avec effets additifs s'est ajusté le mieux pour le revenu, tandis que le niveau d'éducation ne s'est ajusté à aucun des modèles testés.

En conclusion, notre recension systématique indique que la position socio-économique au début du parcours de vie est associée à la pratique d'activité physique à l'âge adulte.

Les résultats de nos deux recherches originales suggèrent un patron d'associations le mieux représenté par le modèle d'accumulation de risque avec effets additifs.

Mots-clefs:

Santé publique, Épidémiologie, Parcours de vie, Position socio-économique, Statut socio-économique, Éducation, Classe sociale, Activité physique, Exercice, Activité motrice

ABSTRACT

Physical activity enhances health, yet only 4.8% of adults in Canada meet the recommended level. Among the determinants of physical activity, socioeconomic position shows some of the strongest and most consistent associations. Its association is found cross-sectionally during adolescence and cross-sectionally during adulthood. This thesis aimed to determine if there is a long-lasting, life course association between socioeconomic position early in life and physical activity during adulthood. If there was one, a second goal was to determine which theoretical model in life course epidemiology best described its pattern.

This thesis comprises three papers: a systematic review and two original contributions. In the systematic review, Medline and EMBASE were searched for studies that assessed socioeconomic position before age 18 years and physical activity at age ≥18 years. In the two original research papers, structural equation modeling was used to compare three competing models in life course epidemiology: the accumulation of risk model with additive effects, the accumulation of risk model with trigger effect, and the critical period model. Each of the original research paper used data from a large, nationally representative prospective cohort. In the first paper, models were compared in the 1970 British birth cohort (n=16,571). Social class was used as an indicator of socioeconomic position, and physical activity was assessed during leisure time, during transports, and at work. In the second paper, models were compared in the Canadian National Longitudinal Survey of Children and Youth (n=16,903). Education and income

were used as indicators of socioeconomic position and physical activity was assessed during leisure-time only.

In the systematic review, 10,619 publications were reviewed by two independent investigators and 42 were retained. For outcome "physical activity" (all types and measures), a significant association with socioeconomic position before age 18 years was found in 26/42 studies (61.9%). When the only outcome considered was leisure-time physical activity, a significant association was found in 21/31 studies (67.7%). In a subset of 21 studies with more rigorous methodology, proportions of studies finding an association were higher: 15/21 (71.4%) for all types and measures of physical activity and 12/15 (80%) for leisure-time physical activity only. In our first original research paper, using British data on social class, we found that the accumulation of risk model with additive effects fit the data best in both men and women for all three domains of physical activity studied (leisure time, transports, and work). In our second original research paper, using Canadian data on leisure-time physical activity, we found that in men, the critical period model fit the data best for education and income, while in women, the accumulation of risk model with additive effects fit the data best for income, whereas education did not fit any model.

To conclude, our systematic review suggests that socioeconomic position early in life is associated with physical activity during adulthood. Results from our two original research papers indicate that the pattern of its association may be best represented by the accumulation of risk model with additive effects.

Keywords:

Public health, Epidemiology, Life course, Socioeconomic position, Socioeconomic status, Education, Social class, Physical activity, Exercise, Motor activity

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LIST OF ABBREVIATIONS

CFI = Comparative fit index

HIV = Human immunodeficiency virus

IPAQ = International physical activity questionnaire

LTPA = Leisure-time physical activity

PA = Physical activity

RMSEA = Root mean squared error of approximation

SE = Standard error

SEP = Socioeconomic position

SC = Social class

SPSS = Statistical Package for the Social Sciences

TLI = Tucker Lewis index

USA = United States of America

UK = United Kingdom

VO_2 max = maximal oxygen consumption

Je dédie cette thèse aux victimes des inégalités sociales

"Exercise is necessary for all except those actually and acutely ill, at all ages, for both sexes, daily, in amount just short of fatigue."
-Dr FC Smith, US Surgeon General's Office, 1915

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Carl-Etienne Juneau

SECTION 1 — INTRODUCTION

1.1 — Physical activity, health, and the public health burden of physical inactivity

Physical activity enhances health (Warburton et al., 2006). The minimum recommended is 30 minutes of moderate intensity physical activity on 5 or more days a week (Haskell et al., 2007). Only 4.8% of Canadian adults meet this recommendation (Colley et al., 2011a), whereas only 6.7% of Canadian youth meet the level recommended for them (60 minutes of moderate intensity physical activity, at least 6 days a week) (Colley et al., 2011b). Thus, due to low physical activity levels, most Canadians are at higher risk of cardiovascular diseases (hypertension, stroke, and heart diseases), cancers (colon cancer, breast cancer, and lung cancer), metabolic disorders (obesity and diabetes), musculoskeletal diseases (sarcopenia and osteoporosis), and psychiatric disorders (anxiety and depression) (Kesaniemi et al., 2001; Tardon et al., 2005; Warburton et al., 2006). As a result, in Canada, direct health care costs attributed to physical inactivity amount to $1.6 billion per year, while indirect costs have been estimated at $3.7 billion (Katzmarzyk and Janssen, 2004). This represents 2.6% of total health care costs.

The public health burden of physical activity in not limited to Canada. In 2009, the World Health Organization ranked physical inactivity as the 4th leading risk factor for global mortality. Physical inactivity is responsible for 3.2 million deaths each year, or 6% of all deaths (World Health Organization, 2009). More deaths were attributable to physical inactivity than to overweight and obesity (ranked 5th) or high cholesterol (ranked 6th).

1.2 — Socioeconomic position as a key correlate of physical activity

Physical activity is a complex behaviour, with many correlates at the individual, environmental, and social levels (Bauman et al., 2012). At the individual level, correlates include age, sex, health status, self-efficacy, job strain, stress, intention to exercise, and previous physical activity. At the environmental level, correlates include access to recreation facilities, transportation environment (e.g. pavement and safety of crossings), and aesthetic environmental variables (e.g. greenness and rated attractiveness) (Bauman et al., 2012). At the social level, correlates include socioeconomic position (e.g. educational attainment and ethnic origin) and social support (Bauman et al., 2012).

In a systematic review, Trost et al. (2002) highlighted the role of socioeconomic position as a key correlate of physical activity. They found that: "Of the six classes of 'determinants' examined, individual-level variables such as socioeconomic status and perceived self-efficacy demonstrated the strongest and most consistent associations with physical activity behavior" (Trost et al., 2002). Indeed, systematic reviews have established that socioeconomic position is associated with physical activity cross-sectionally during adolescence (Stalsbergs and Pedersen, 2010) and cross-sectionally during adulthood (Gidlow et al., 2006).

1.3 — Nature of the association between socioeconomic position and physical activity

Are the associations between socioeconomic position and physical activity during adolescence and adulthood purely cross-sectional? Or is there a long-lasting, life course association between socioeconomic position early in life and physical activity during adulthood? If there is a life course association, to what extent is it mediated by socioeconomic position during adulthood? Are the associations during adolescence and adulthood independent and additive? Or is the association for adolescence entirely mediated by socioeconomic position during adulthood? A life course association between socioeconomic position early in life and physical activity during adulthood seems plausible, as systematic reviews have found evidence of similar associations for two health outcomes in adulthood closely related to physical activity: obesity (Senese et al., 2009) and cardiovascular disease (Pollitt et al., 2005). If there is indeed a long-lasting, life course association between socioeconomic position during early in life and physical activity during adulthood, and if this association is regarded as causal, childhood might prove a relevant target for interventions on social determinants of health aimed at increasing physical activity later in life. Arguably, the potential for prevention is greater for childhood, as an increase in physical activity during childhood is likely to be maintained throughout the life course (Malina, 2001). Thus, public health practitioners may want to target socioeconomic position during childhood to increase physical activity across the life course and, ultimately, lower risks of cardiovascular disease, cancer, mental health, and every other health correlates of physical activity (Warburton et al., 2006). This would have the double benefit of 1) reducing the public health and economic burdens of physical inactivity and 2) contribute to the reduction of social inequalities in health, a key priority at the international (CSDH, 2008) and Canadian levels (Senate Subcommittee on Population Health, 2009).

SECTION 2 — RESEARCH GOALS

2.1 — Overarching goal: Is there a life course association?

The overarching goal of this thesis was to determine if there is a life course association between socioeconomic position early in life and physical activity during adulthood. If there was one, a second goal was to determine which theoretical model in life course epidemiology best described its pattern.

2.2 — Specific goal 1: Does the literature support this hypothesis?

Our first goal was to determine if the literature supported the hypothesis that there is a life course association between socioeconomic position early in life and physical activity during adulthood. This goal was achieved by carrying out a systematic review. A secondary aim of this systematic review was to highlight the methodological limitations most commonly found in this body of literature to make recommendations to strengthen future research.

2.3 — Specific goal 2: Which model in life course epidemiology best describes this association?

Our second goal was to determine which theoretical model in life course epidemiology best described the pattern of associations between socioeconomic position across the life course and physical activity during adulthood. This goal was accomplished by carrying out original research. In doing so, we also aimed to improve on the methodological limitations highlighted in our systematic review. Three theoretical models in life course epidemiology were examined: the accumulation of risk model with additive effects, the accumulation of risk model with trigger effect, and the critical period model. Following the accumulation of risk model with additive effects, we hypothesized that socioeconomic position during childhood, during adolescence, and during adulthood are associated with physical activity during adulthood directly, irrespective of later exposure (an independent association) and also indirectly through socioeconomic position later in life (mediation).

SECTION 3 — LITERATURE REVIEW

3.1 — Physical activity and health

Morris et al. (1953) are credited for publishing one of the first studies linking physical activity to health. In their 1953 study published in *The Lancet*, they found that London bus, tram, and trolleybus conductors (who climbed 500 to 750 steps per day) had a lower annual incidence of coronary artery disease than drivers (who sat for over 90% of their shifts) (Morris et al., 1953).

Physical activity can also extend life. In another seminal study, Paffenbarger et al. (1986) followed up a cohort of 16,936 Harvard alumni for 12-16 years between 1962 and 1978. Cohort members were aged 35 to 74 years at baseline. Results showed that "by the age of 80, the amount of additional life attributable to adequate exercise, as compared with sedentariness, was one to more than two years." This study was published in the *New England Journal of Medicine*.

The studies by Morris et al. (1953) and Paffenbarger et al. (1986) were observational, as is most of the evidence base linking physical activity to health (Dishman et al., 2012; p. 89). Because of selection bias, observational studies are generally regarded as producing evidence of lower quality than randomized controlled trials (Hannan, 2008). Unfortunately, few randomized controlled trials of adequate design have been carried out in the general, healthy population to confirm the health benefits of physical activity in healthy adults (Haskell et al., 2007; Bize et al., 2007). However, there is evidence from randomized controlled trials of coronary heart disease patients reporting lower mortality for physically active groups, thereby supporting the notion that physical activity does indeed extend life in the general, healthy population (Taylor et al., 2004). This evidence has been reviewed in a meta-analysis of 48 trials involving 8,940 patients (Taylor et al., 2004). Patients were assigned to cardiac rehabilitation that included exercise or to usual care without exercise: meta-analysis found an odds ratio for total mortality of 0.80 among patients who exercised (95% CI: 0.68-0.93) (Taylor et al., 2004).

3.2 — Social inequalities in health

Social inequalities in health are systematic differences in health between socioeconomic groups (Whitehead and Dahlgren, 2006). When they are deemed unnecessary, avoidable, unfair, and unjust, social inequalities in health have been referred to as "health inequities" (Whitehead, 1992). It could be argued that social inequalities in physical activity are inequitable, as physical activity is a modifiable behaviour that can be readily taken up by people of all socioeconomic backgrounds. Indeed, walking, the most common form of physical activity, is free and can be practiced almost anywhere.

As early as 1848, Virchow had noted that socioeconomic position seemed to influence the distribution of infectious epidemics, like typhus. He reportedly concluded that: "Medicine is a social science and politics nothing but medicine on a grand scale" (quoted in Rosen, 1979; p. 29; House, 2002). However, Virchow's insight was undermined in the last third of the nineteenth century, as Louis Pasteur (in France) and Robert Koch (in Germany) enunciated the germ theory of disease (Kunitz 1987; Kunitz, 2006). The germ theory of disease and the birth of bacteriology steered medicine and epidemiology towards a biological conception of health and disease risk; this "biomedical hegemony" would remain for much of the twentieth century (House, 2002).

In 1980, publication of the Black report (Department of Health and Social Security, 1980) signaled a renewed interest in the social determinants of health. The Black report reviewed differences between occupational classes in mortality, morbidity, and use of health services in the UK (MacIntyre, 1997). It also offered four explanations for these differences: (1) "artefact" (of measurement); (2) "natural/social selection" (people in good health achieve higher socioeconomic position); (3) "materialist/structural" (physical and psychosocial features related to class structure shape the class gradient in health); and (4) "cultural/behavioural" (people up the social hierarchy adopt better health behaviours) (MacIntyre, 1997). According to MacIntyre (1997), the authors of the Black report: "rejected the 'hard' [...] versions of the first three [explanations] and espoused the 'soft' version of the last." Indeed, as social inequalities in health were found consistently over time and in diverse populations, the artefact explanation was ruled out. The social selection explanation has lost support, although some authors note that it remains "plausible" (Adler et al., 2012). Remaining are the materialist/structural and the cultural/behavioural explanations. There is evidence that both contribute to social inequalities in health, with a minor contribution from social selection (Goldman, 2006).

Perhaps the most famous study of social inequalities in health is the Whitehall Study (Marmot et al., 1978). This study examined the association between grade of employment, coronary risk factors, and coronary heart disease in 17,530 civil servants working in London. Civil servants were examined between 1967 and 1969 and followed up for 7.5 years. Results showed that grade of employment was inversely related to coronary heart disease mortality. Strikingly, grade of employment was a stronger predictor of coronary heart disease than all of the following risk factors combined: height, weight for height, blood pressure, plasma glucose, smoking, and leisure-time physical activity. Men in the lowest grade (messengers) had 3.6 times the coronary heart disease mortality of men in the highest employment grade (administrators). After adjusting for these risk factors (plus plasma cholesterol), the inverse association between grade of employment and coronary heart disease mortality remained strong. These risk factors explained only approximately 40% of the grade difference in coronary heart disease, leaving 60% unaccounted for. The authors concluded by hypothesizing that psychosocial differences between the grades might explain the gradient. This was supported by subsequent research in the Whitehall II study (Marmot et al., 1997). Adler et al. (1994) highlighted that the materialistic explanation failed to account for the persistent gradient at all levels of the socioeconomic hierarchy. Severe poverty surely had negative effects on health, through poor nutrition, crowded living conditions, and inadequate medical care. However, poverty could not be blamed for the gradient. Neither could poverty explain either why those at the highest level enjoyed better health than those just below, as was the case in the Whitehall studies (in which no civil servant was exposed to poverty). This led Adler et al. (1994) to search for "factors that can account for the link to health all across the socioeconomic status hierarchy." They offered three explanations. First, the gradient may be a spurious association arising from the association of both socioeconomic position and health outcomes to underlying genetic factors. Second, social selection processes may be at work. Third, socioeconomic position may affect biological functions that, in turn, influence health status. Adler et al. (1994) provided evidence against the first two explanations and expanded on the third. They argued that socioeconomic position could affect biological functions through components that "shape one's life course and are enmeshed in key domains of life." Those included: the physical environment, the social environment, health behaviours, and "socialization and experiences that influence psychological development and ongoing mood, affect, and cognition." This broad category included factors such as smoking, physical activity, alcohol, depression, hostility, psychological stress, and the effects of social ordering. Access to health care was excluded, as the same group had concluded elsewhere that it could not explain the gradient (Adler et al., 1993). The authors concluded with a reminder that while social class is among the strongest known predictors of illness, it was yet a variable about which very little was known.

Research and political concern into social inequalities in health culminated in 2008 when the World Health Organization published its report *Closing the gap in a generation: Health equity through action on the social determinants of health*. This report noted that there are marked social inequalities in health within and between countries. For example, within the U.S., high-risk urban black men had a 15.4-year life expectancy gap when compared to Asian men (high-risk Blacks: 66.3 years; Asians: 81.7 years) (Murray et al. 2006). Inequalities between countries are more pronounced, the largest being a 42-year life expectancy gap between newborn females in Japan and in the African state of Lesotho (CSDH, 2008). While these examples are extreme, they reflect a global phenomenon. The report called for closing the health inequity gap around the world in one generation (CSDH, 2008). This call was echoed in 2009 by the Canadian Senate (Senate Subcommittee on Population Health, 2009) and by other official governmental bodies across the globe (U.S. Department of Health and Human Services, 2010; U.K. Department of Health, 2010; Commonwealth of Australia's Standing Council on Health, 2013; Statens folkhälsoinstitut Socialstyrelsen, 2013). Social inequalities in health and health inequities are thus a key public health priority both at the international and Canadian levels.

3.3 — Cross-sectional associations between socioeconomic position and physical activity

3.3.1 — During childhood

Are social inequalities in physical activity found in children? From what age is socioeconomic position associated with physical activity? Four reviews have tried to answer this question (Gorely et al., 2004; Gustafson and Rhodes, 2006; Van Der Horst et al., 2007; Hinkley et al., 2010).

Van Der Horst et al. (2007) reviewed 60 studies on correlates of physical activity in children (aged 4-12 years) and adolescents (aged 13-18 years). Parental education was not associated with physical activity in children (it was associated with physical activity in adolescents, however).

Gustafson and Rhodes (2006) reviewed 34 studies of parental correlates of physical activity in children. They reported that: "There were not enough studies to draw conclusions about family socioeconomic status" as a correlate of physical activity in children.

Hinkley et al. (2010) reviewed 29 studies that examined correlates of sedentary behaviours in preschool children. Parental education had "an indeterminate association" with sedentary behaviour as measured by accelerometry. Most correlates "had been investigated too infrequently to be able to draw robust conclusions about associations." The authors concluded that correlates of preschool children's sedentary behaviours are not well established.

Gorely et al. (2004) reviewed 68 studies of correlates of television viewing among youth (aged 2-18 years). Parental income and education were inversely associated with TV viewing (high income and education, less TV viewing). While this finding seems to support the notion that children from high income or education families are more physically active, it should be noted that less TV viewing does not necessarily indicate more physical activity. In their systematic review and meta-analysis, Marshall et al. (2004) found a "small but negative" association between TV viewing and physical activity (the mean sample-weighted effect size between TV viewing and physical activity was -0.096 [95% CI=-0.080 to -0.112; total n=141,505 from 39 independent samples]). The authors concluded that: "While the total amount of time per day engaged in sedentary behavior is inevitably prohibitive of physical activity, media-based inactivity may be unfairly implicated in recent epidemiologic trends of overweight and obesity among children and youth. Relationships between sedentary behavior and health are unlikely to be explained using single markers of inactivity, such as TV viewing or video/computer game use."

Overall, these reviews suggest that there is no clear association between parental socioeconomic position and physical activity or sedentary time in children.

3.3.2 — During adolescence

Socioeconomic position does not appear to be associated with physical activity in children (Van Der Horst et al., 2007; Gustafson and Rhodes, 2006). Does this association emerge in adolescence? Stalsbergs and Pedersen (2010) have tried to answer this question in a systematic review.

They concluded that: "The main results support the hypothesis that there is an association between socioeconomic status and physical activity among adolescents, and that adolescents with higher socioeconomic status are more physically active than those with lower socioeconomic status" (Stalsbergs and Pedersen, 2010). Inclusion criteria for this systematic review were: studies based on original data, including those based on national surveys, articles written in English, empirical studies, and age limited to the rage of 13-18 years. Search identified 3928 papers; 62 met all criteria and were included for review. Out of these 62 studies, 36 (58%) found increasing physical activity with increasing socioeconomic position, 20 (32%) did not find an association, and six (10%) found an inverse association. These results suggest that there is an association between socioeconomic position and physical activity before adulthood, during adolescence.

3.3.3 — During adulthood

There is no clear association between socioeconomic position and physical activity in children (Van Der Horst et al., 2007; Gustafson and Rhodes, 2006). However, by adolescence, these two variables are associated (Stalsbergs and Pedersen, 2010). Are they associated in adulthood as well?

Numerous reviews have listed socioeconomic position as a correlate of physical activity in adults (Trost et al., 2002; Seefeldt et al., 2002; White et al., 2005). The association between these two variables was confirmed in a systematic review by Gidlow et al. (2006).

Gidlow et al. (2006) carried out a systematic review of socioeconomic position and physical activity during adulthood. Inclusion criteria were: English language, published in a peer-reviewed journal, report of a recognized socio-economic outcome (social class, income, education, asset-based, or based on area of residence), report of physical activity as a separate outcome, original study (reviews were excluded), adult populations (age ≥ 16 years, at baseline if longitudinal), and conducted in Western countries to limit cultural differences. A total of 5292 studies were found; 33 met all criteria and were included for review. A positive association (physical activity increased as socioeconomic position increased) was found for social class in 9 out 10 studies (90%), for education in 17 out of 24 studies (71%), for income in 11 out of 18 studies (61%), for asset-based measures in 1 out of 2 studies (50%), and for area-based measures in 3 out of 3 studies (100%). The authors concluded that: "There was consistent evidence of higher prevalence or higher levels of leisure-time or moderate-vigorous physical activity in those at the top of the socio-economic strata compared with those at the bottom."

In summary, based on the literature we have reviewed so far, we can conclude that socioeconomic position and physical activity are not associated during childhood (Van Der

Horst et al., 2007; Gustafson and Rhodes, 2006), but that they are associated during adolescence (Stalsbergs and Pedersen, 2010) and during adulthood (Gidlow et al., 2006).

3.4 — Social inequalities in physical activity in Canada

We have seen that socioeconomic position is associated with physical activity during adulthood (Gidlow et al., 2006). This systematic review included all the available evidence published in English. It is based on an international body of evidence, and the conclusions it draws have external validity based on this international study sample. But do they apply to Canada? Is socioeconomic position associated with physical activity in Canada?

Four early studies on Canadian samples suggest that they are (Millar and Wigle, 1986; Millar and Stephens, 1991; Pomerleau et al., 1997; Choinière et al., 2000). In addition, two more recent studies on trends (Craig et al., 2004; Smith et al., 2009) suggest not only that Canadians at the bottom of the social hierarchy are less physically active than their more fortunate counterparts, but also that this gap is widening.

The first study of social inequalities in Canada was published in 1986 by Millar and Wigle (1986). They used data from the 1981 Canada Fitness Survey (n=23,500). In this survey, physically inactive respondents were those who were not active in their leisure time at least 3 hours per week, at least 9 months per year. Education was defined as the highest completed grade: elementary, secondary, or university/college. The authors compared the age-standardized prevalences of leisure-time physical inactivity across groups and found that less educated Canadian men and women were more inactive than their more educated counterparts.

In perhaps the first study of trends in physical inactivity inequalities in Canada, Millar and Stephens (1993) compared data from the 1985 and 1991 General Social Surveys. Respondents were stratified by education: less than high school, high school graduate, post-secondary other than university, and university graduate. Using “extreme groups” (lowest vs. highest educational attainment) ratios to measure inequalities, the authors concluded that social inequalities in physical inactivity by education narrowed for men and women between 1985 and 1991. Differences in the measurement of leisure-time physical inactivity between the two General Social Surveys limit the validity of their conclusion, however.

Pomerleau et al. (1997) analyzed data from the 1990 Ontario Health Survey (n=61,239). Their outcome was self-reported leisure-time physical activity. Participants were categorized as active or inactive based on their energy expenditure, estimated from their self-reported number, frequency, and duration of physical activities during the previous month. Four measures of socioeconomic position were used: educational achievement, household income status, source of household income, and occupational prestige. Leisure-time physical activity was inversely associated with all measures of socioeconomic position, except source of household income. Source of household income was a measure with two categories, based on the household receiving (or not) family benefits as a source of income (an indication of very low income). The association of physical activity with this variable was not significant. However, the association was significant for household annual income status, a measure based on dollar amount in this study. Differences in measurement likely explain the discrepancy in results for income. As physical activity was also inversely associated with the other two measures of socioeconomic position in this study (educational achievement and occupational prestige), overall, these results support the notion that socioeconomic position and physical activity are inversely associated in Canada.

Choinière et al. (2000) have shown that less educated Canadian men and women were more inactive than their more educated counterpart, while the same relationship by income held true for men only. They analyzed cross-sectional data from the Canadian Heart Health Database gathered between 1986 and 1992 (n=23,129). Respondents were considered inactive if they had not engaged in leisure-time physical activity at least once a week during the previous month. Education was defined as the highest grade completed. Categorizes were: secondary school not completed, secondary school completed, and university degree obtained. Household income was also divided in three categories: low (1 or 2 people making less than $12,000 or 3 or more people making less than $25,000), middle (one person making between $12,000 and $24,999, two people making between $12,000 and $49,999, or three or more people making between $25,000 and $49,999), or high (one person making $25,000 or more, or two or more people making $50,000 or more). The authors compared the age-standardized prevalences of leisure-time physical inactivity across groups.

Craig et al. (2004) examined 20-year trends in physical activity in Canadian adults. They used data from six national surveys conducted between 1981 and 2000, with sample sizes ranging from 2,500 to 18,000. Overall, they found physical activity levels increased over time for men and women in all age, education, and income groups. However, their data indicate social inequalities by education and income increased during that period. Absolute differences between lowest and highest education groups in percentage meeting the recommended physical activity level increased from 11.6% (in 1981) to 16.5% (in 2000). In addition, absolute differences between lowest and highest income groups increased as well, from 3.4% (in 1981) to 20.2% (in 2000). In multivariate analyses adjusted for age, sex, income, and education, odds of meeting the recommended physical activity level for the highest (vs. lowest) education group decreased slightly from 1.99 (in 1981) to 1.41 (in 2000). However, for income, the odds increased markedly from 0.97 (in 1981) to 2.39 (in 2000). In summary, between 1891 and 2000, absolute differences increased for both education and income, while relative differences adjusted for confounders narrowed slightly for education, and increased markedly for income. Overall, these result suggest social inequalities in physical activity have widened in Canada between 1981 and 2000, except for a slight decrease in relative inequalities by education.

Smith et al. (2009) examined trends in social inequalities in physical activity in Canada between 1981 and 2005. They focused on inequalities by education. They used data from four nationally representative surveys. Analyses were restricted to adults aged 25 to 64 years, and were stratified by sex. Sample sizes for men ranged from 5,155 (in 1981) to

36,297 (in 2005). Sample sizes for women ranged from 6,769 (in 1981) to 41,739 (in 2005). They found social inequalities by education narrowed between 1981 and 1996, and widened between 1996 and 2005. Trends were similar for both their absolute (prevalence ratios and absolute concentration index) and relative (relative concentration index) measures of social inequalities. These results add to Craig et al. (2000)'s results, suggesting that social inequalities in physical activity are growing in Canada.

3.5 — A life course perspective on the association between socioeconomic position and physical activity

The life course perspective was first established in sociology in the 1970s, before gaining popularity in public health research, especially since the year 2000 (Mayer, 2009). It is a scientific idea, a theoretical orientation, an approach and an interdisciplinary field of research (Billari, 2009).

In life course research: (1) changes in human lives are considered over long periods of the lifetime, (2) there is the assumption that prior life history has strong influences on outcomes later in life, (3) changes over the life course are analyzed as the outcome of personal characteristics, individual action, cultural frames, institutional influences, and structural conditions (relating micro, meso, and macro levels of analysis, structure, and agency) (Mayer, 2009).

Following the logic of the life course perspective, individual, historical, economic, political, cultural, and family contexts are likely to influence physical activity behaviour in adults. Since they are thought to have a subtle, cumulative, and long-lasting influence on behaviour, their potential influence should be studied from a life course perspective (Mayer, 2009). In public health, the life course perspective has lead to the development of life course epidemiology (Kuh and Ben-Shlomo, 1997).

3.6 — Life course epidemiology

Life course epidemiology is the study of long term effects on later health or disease risk of physical or social exposures during gestation, childhood, adolescence, young adulthood and later adult life (Kuh et al., 2003). Life course epidemiology gained in popularity in the 1990s in the face of accumulating evidence indicating that many diseases typically diagnosed in adulthood have antecedents earlier in life (Blane, 2007, Liu 2010). Perhaps most well known is the work of Barker and Osmond (1986), which related exposures in the prenatal environment and childhood nutrition to long-term increases in ischaemic heart disease risk. This body of work is now known as the "fetal origins hypothesis" (Lynch and Davey Smith, 2005).

Indeed, cardiovascular diseases appear to be a case in point. In a systematic review, Galobardes et al. (2006) reported that 31 out of 40 studies "found a robust inverse association between childhood circumstances and cardiovascular disease risk." Across studies, the association was stronger for stroke. For example, using data for 3,750 subjects surveyed during their childhood in England and Scotland between 1937 and 1939 and followed up until 1997, Frankel et al. (1999) found an age-adjusted hazard ratio of stroke of 2.89 for subjects whose father was unemployed vs. those whose father was a skilled worker (social class III). The trend across father social class groups during childhood was significant ($P < 0.01$) and remained so after adjustment for the Townsend deprivation index of area of residence during adulthood, suggesting that socioeconomic status during childhood is associated with stroke independently of socioeconomic status during adulthood. These associations are not limited to cardiovascular diseases or stroke, however, as other systematic reviews have concluded that mortality during adulthood from multiple causes is influenced by exposures in utero and during childhood (Galobardes et al., 2004; Galobardes et al., 2008).

Life course epidemiology includes the study of behavioural risk factors, such as physical activity. In life course epidemiology, chronic exposure to behavioural risk factors is seen as a "pathway that operates across an individual's life course to influence the development of chronic diseases" (Ben-Shlomo and Kuh, 2003). The "pathway" for physical activity is likely to operate across an individual's life course, as tracking studies have shown that physical activity is relatively stable through the life course (Malina, 2001; Telama et al. 2005).

Tracking refers to the tendency of individuals to maintain their position within a group over time (Malina, 2001). It is assessed by correlating each individual’s position within the group at two points in time using Pearson’s or rank order correlations (Malina, 2001). Thus, high tracking implies that the active stay active, the moderately active stay moderately active, and the inactive stay inactive (Malina, 2001).

In the longest published tracking study of physical activity, Telama et al. (2005) followed a cohort of 2,309 young Finns for 21 years. Subjects were aged 9-18 years at baseline (in 1980). They were aged 30-39 years at follow-up (in 2001). Tracking was moderate in men ($r = 0.33$ to 0.44, all $p < 0.01$) and low in women ($r = 0.14$ to 0.26, $p > 0.05$ to < 0.01). Using logistic regression, Telama et al. (2005) also found that subjects who remained in the most active tertiles in 1980, 1983, and 1986 ("persistent physical activity") were much more likely to be active in 2001 when compared to those who were in the least active tertiles in 1980, 1983, and 1986.

In life course epidemiology, conceptual models are used to illustrate the hypothetical relationships between exposures across the life course and health outcomes later in life. These models have been referred to as life course models (Kuh et al., 2003). Three main models are proposed in the literature on life course epidemiology (Ben-Shlomo and Kuh, 2002). These models are: (1) the accumulation of risk model with additive effects, (2) the accumulation of risk model with trigger effect, and (3) the critical period model (Ben-Shlomo and Kuh, 2002).

The first two models (the accumulation of risk model with additive effects and the accumulation of risk model with trigger effect) are "chains of risk" models (Ben-Shlomo and

Kuh, 2002; Kuh et al., 2003; Lynch and Davey Smith, 2005). In chains of risk models, exposure at each point in time (e.g. low socioeconomic position during childhood) increases risk of the following exposure (e.g. low socioeconomic position during adulthood).

There are two kinds of chains of risk. If socioeconomic position during childhood influences physical activity during adulthood independently of socioeconomic position during adulthood, then this relationship would be best conceptualized as an "additive effects chain of risk" (figure 3, model a). In an additive effects chain of risk, each exposure (such as poor socioeconomic position during childhood, during adolescence, and during adulthood) has an independent effect on the outcome measure (such as physical activity during adulthood). This chain of risk model is illustrated in a study by Davey Smith et al. (1997).

In this prospective observational study, 5,766 men aged 35-64 years at baseline were followed up for 21 years (Davey Smith et al., 1997). Information was collected about social class at three stages of participants' lives: the social class of their father, the social class of their first job, and the social class of their job at the time of screening. This information was used to create an indicator of "cumulative social class", ranging from non-manual social class at all three stages of the life course to manual social class at all three stages. For this indicator of cumulative social class, the distribution seemed to follow a chain of risk model, as the largest category consisted of men exposed to manual social class at all three stages of their life course (their father had had a manual job, their own first job had been manual, and they had a manual job at the time of screening). A total of 2,319 out of 5,567 men (41.66% of the sample) were in this category. However, no statistical tests were performed on the distribution of social class in the sample.

In this study, there was a graded association between cumulative exposure to manual social class and all-cause and cardiovascular mortality. For all-cause mortality, age-adjusted death rates per 1,000 person-years were 100.1, 123.4, 135.1, and 153.9 for exposure to manual social class at zero, one, two, or three stages of the life course, respectively. Corresponding relative death rates (95% CI) adjusted for age and risk factors were 1, 1.30 (1.08 - 1.57), 1.33 (1.11 - 1.60), and 1.57 (1.33 - 1.85) (p for trend <0.0001). Therefore, in this study, the association between all-cause mortality and manual social class followed an additive effects chain of risk, as men exposed to manual social class at one, two, or three stages of their life course had cumulatively greater risk of mortality (Davey Smith et al., 1997).

The other chain of risk model is the "trigger effect chain of risk". In a trigger effect chain of risk, each exposure increases risk of the following exposure, while only the last exposure (socioeconomic position during adulthood) affects ("triggers") the outcome measure (Kuh et al., 2003). For socioeconomic position and physical activity, if socioeconomic position during childhood does not influence physical activity during adulthood independently of socioeconomic position during adulthood, then we would best conceptualize this relationship as a "trigger effect chain of risk" (figure 3, model b).

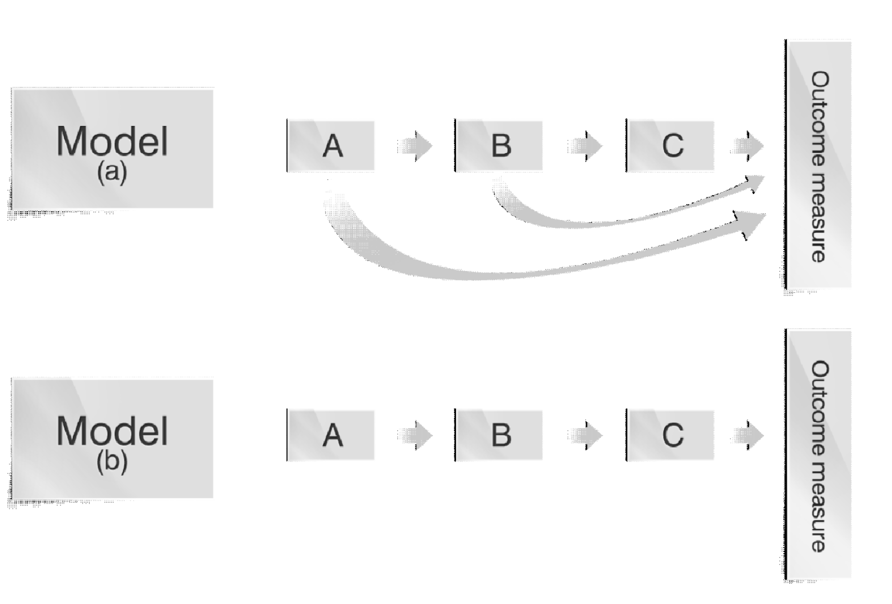

Figure 1 – Life course models: (a) additive effects chain of risk and (b) trigger effect chain of risk. Adapted from Kuh et al. (2003).

In their theoretical paper, Ben-Shlomo and Kuh (2003) give an example of a trigger effect chain of risk. In this example, unemployment will increase likelihood of financial insecurity, which in turn will increase likelihood of marital conflict, which in turn will increase likelihood of physical abuse, which in turn will ultimately increase likelihood of divorce. In this chain of risk, if only physical abuse leads to divorce, there is a trigger effect.

Within each chain of risk (with additive or trigger effect), subsequent socioeconomic position may mediate or modify the association between socioeconomic position earlier in life and physical activity during adulthood (Kuh et al., 2003). Chains of risk are part of the accumulation of risk models, which focus on the total amount or sequence of exposure

(Lynch and Davey Smith, 2005). The other main life course model is the critical period model, which emphasizes the timing of exposure.

Exposure occurring during a critical period has long-lasting effects on anatomical structure or physiological function, leading to unalterable biological development and increased risk of disease (Lynch and Davey Smith, 2005). Within the critical period model, exposures having a more subtle, yet long-lasting influence that is magnified more than the effect of the same exposure during another time period are referred to as occurring during a sensitive period (Lynch and Davey Smith, 2005). The fetal origins of adult disease hypothesis is an example of a critical period model (Barker, 1995).

The fetal origins of adult disease hypothesis is based on the observation that brief periods of undernutrition during fetal development may permanently reduce the number of cells in a particular organ (Widdowson and McCance, 1975). In addition, undernutrition during fetal development can cause disproportionate growth of different tissues, because different tissues have critical periods of growth at different times. Thus, according to this hypothesis, fetal undernutrition in middle to late gestation, which leads to disproportionate fetal growth, causes a marked, unalterable increase in later coronary heart disease. Hypothesized mechanisms included the programming of blood pressure, insulin responses to glucose, cholesterol metabolism, blood coagulation, and hormonal settings (Barker, 1995).

Critical period models do not completely exclude accumulation of risk. Likewise, accumulation of risk models allow for developmental periods during which susceptibility may be greater (Ben-Shlomo and Kuh, 2002; Lynch and Davey Smith, 2005). Moreover, at the outset, it is usually unclear which model applies for any given health outcome. A major challenge in life course epidemiology is therefore to disentangle these competing life course models and to determine which life course model best fits the data. Yet, as many authors have commented (Ben-Shlomo and Kuh, 2002; Hallqvist et al., 2004; De Stavola et al., 2006; Dahly et al., 2009; Gamborg et al., 2009; Mishra et al., 2009; Kaakinen et al., 2010; Murray et al., 2011), the statistical methods traditionally used in epidemiology are ill-suited for this task. In the past, traditional regression-based techniques such as multiple and logistic regression have been used extensively to analyze life course data. These statistical techniques do not allow for formal testing of competing life course models. Therefore, they do not translate well into practice the full conceptual richness of life course epidemiology. In recent years, this has lead some authors to propose the use of statistical methods that do allow competing models to be tested statistically, such structural equation modeling (Ben-Shlomo and Kuh, 2002; Hallqvist et al., 2004; De Stavola et al., 2006; Dahly et al., 2009; Gamborg et al., 2009; Mishra et al., 2009; Kaakinen et al., 2010; Murray et al., 2011).

To improve on the methodology used so far in this body of literature, a secondary goal of our original research became to contribute to bridging the gap between theory and methods in life course epidemiology, by showing that structural equation modeling can be a helpful tool in selecting among competing theoretical models when analyzing life course data.

Specifically, we aimed to show that structural equation modeling can be used to indicate which life course model best represents the association between socioeconomic position across the life course and physical activity during adulthood.

Despite the methodological challenges in data analysis we have just highlighted, life course epidemiology and its life course models offer promising avenues for understanding the potential influence of socioeconomic position during childhood and across the life course on physical activity during adulthood. It is no surprise, then, that the evidence base on socioeconomic position across the life course and physical activity during adulthood has been strongly influenced by life course epidemiology.

3.7 — Life course associations between socioeconomic position during childhood and correlates of physical activity during adulthood

There is evidence for a life course association between socioeconomic position during childhood and two outcomes during adulthood closely related to physical activity. Two systematic reviews have reached this conclusion, for obesity (Senese et al., 2009) and cardiovascular diseases (Pollitt et al. 2005).

Senese et al. (2009) carried out a systematic review of the association between socioeconomic position during childhood and obesity during adulthood. Inclusion criteria were: exposures examining some aspect of childhood socioeconomic position measured in subjects < 19 years of age, outcomes capturing some aspect of obesity measured in subjects

≥ 19 years of age, adjustment for age, and sample size > 600 participants. A total of 6,607 papers were found; 30 met all criteria and were included for review. Results differed by sex. In age-adjusted analyses, 70% (14 of 20) of studies of females found decreasing obesity during adulthood with increasing socioeconomic position during childhood. In contrast, this association was found in only 27% (4 of 15) of studies in males. These results suggest that socioeconomic position during childhood is associated with obesity during adulthood in females.

Pollitt et al. (2005) carried out a systematic review of life course socioeconomic position and cardiovascular disease. Inclusion criteria were: publication date between January 1966 and July 2003, socioeconomic status or related measures as independent variables, outcomes of subclinical coronary heart disease, cardiovascular morbidity and/or mortality, or traditional cardiovascular risk factors. Behavioral risk factors were limited to: adult diet, physical activity, alcohol consumption, and smoking. Physiological outcomes were: measures of obesity, blood pressure, intima-media thickness, fibrinogen, insulin resistance, dyslipidemia, and lung function. A methodological limitation in the reporting of this systematic review is that the authors did not mention how many articles they found at each stage of the search. They do specify 49 studies met all criteria, however. Their choice of summarizing and reporting study findings were unconventional as well: "Quantitative summarization of the study findings is problematic due to varied study populations, socioeconomic status measures and cardiovascular disease outcomes evaluated, time points evaluated, and design utilized." Thus their analysis "consists primarily of qualitative information on the types and directions of associations observed." They concluded that: "studies reviewed provided moderate support for the role of low early-life socioeconomic status and elevated levels of cardiovascular disease risk factors and cardiovascular disease morbidity and mortality." Thus, these results suggest that socioeconomic position during childhood is associated with cardiovascular risk, disease, and mortality during adulthood, albeit moderately.

Obesity and cardiovascular diseases are closely related to physical activity. Since there is a life course association between socioeconomic position during childhood and obesity and cardiovascular diseases during adulthood, we might hypothesize a similar association for physical activity.

3.8 — Theoretical support for a life course association between socioeconomic position during childhood and physical activity during adulthood

The literature on fundamental movement skills provides theoretical support for a life course association between socioeconomic position during childhood and physical activity during adulthood.

Fundamental movement skills are basic motor skills. They include skills like running and hopping (locomotor skills), catching and throwing (object control), and balancing and twisting (stability) (Lubans et al., 2010). These basic motor skills are usually learned early in life. Later, they are refined into specialized movement sequences specific to each physical activity (Figure 1).

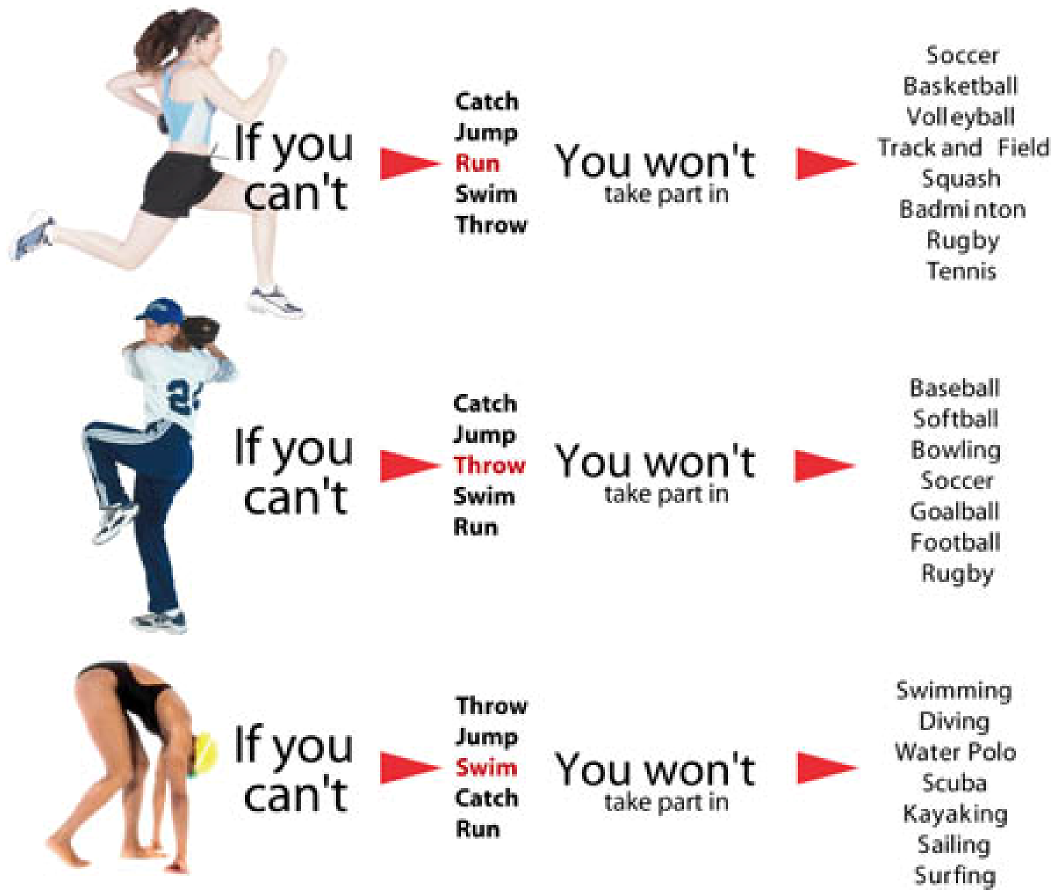

Figure 2 — Fundamental movement skills (left column) learned during childhood are refined later in life into specialized movement sequences specific to each physical activity (right column). Image reproduced with permission from Canadian Sport For Life (2014)

Fundamental movement skills learned during childhood are refined into specialized movement sequences specific to each physical activity later in life. Moreover, fundamental movement skills learning and competency early in life is theorized to be necessary "for adequate participation" in physical activity during adulthood (Lubans et al., 2010). In their systematic review, Lubans et al. (2010) reported that: "Fundamental movement skills are considered to be the building blocks that lead to specialized movement sequences required for adequate participation in many organized and non-organized physical activities for children, adolescents and adults." Fundamental movement skills are the cornerstone of a developmental conceptual model of physical activity participation developed by Stodden et al. (2008).

In their theoretical paper, Stodden et al. (2008) argued that motor skill competence is the main causal variable that drives physical activity participation. They wrote: "The development of motor skill competence is a primary underlying mechanism that promotes engagement in physical activity" (Stodden et al., 2008). In their paper, they presented a conceptual model describing the relationships among physical activity, motor skills competence, perceived motor skills competence, health-related fitness, and obesity. In their developmental model (Figure 2), motor skill competence is a main causal variable, and perceived motor skills competence, health-related fitness, and obesity act as mediating variables.

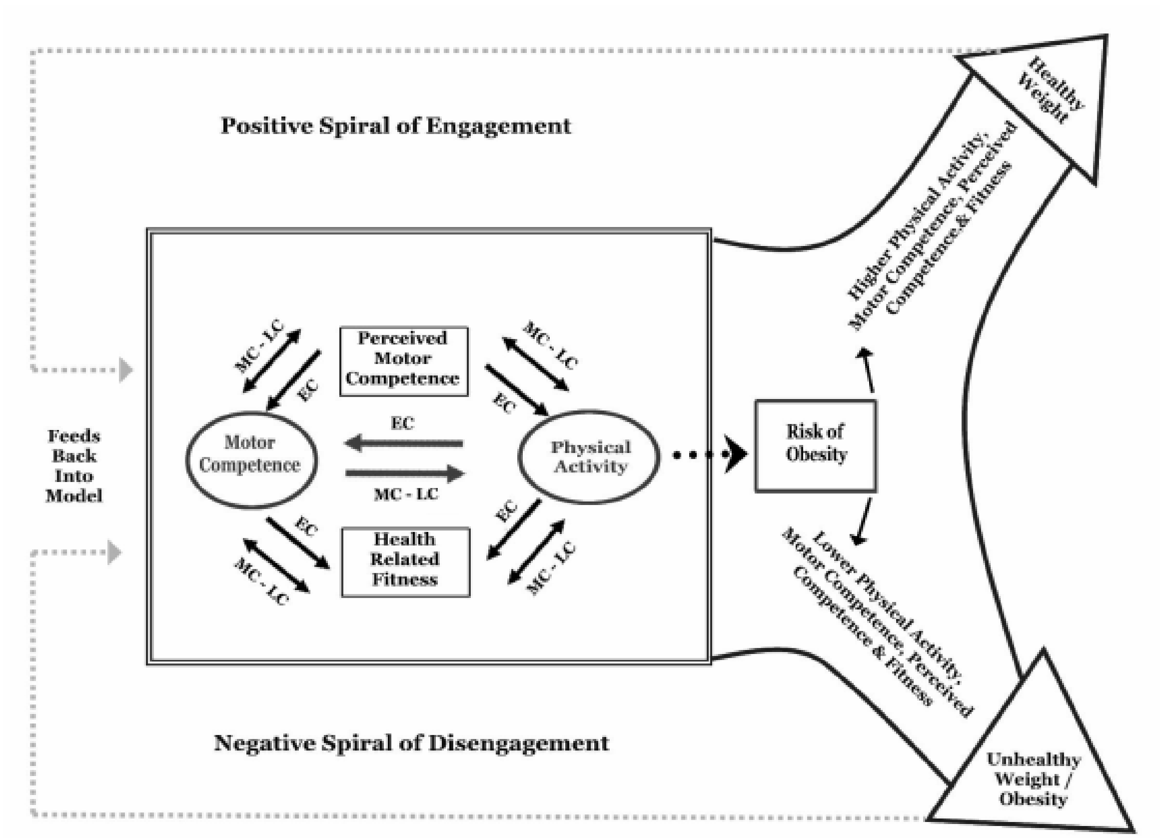

Figure 3 — Stodden et al.'s (2008) developmental model of physical activity participation. Motor competence (inside main box, left) is hypothesized to influence physical activity: (1) directly (middle path), (2) indirectly through perceived motor competence (top path), and (3) indirectly though health-related fitness (bottom path). In turn, physical activity influences risk of obesity (outside of box, right). Obesity then influences physical activity participation, leading to more (or fewer) opportunities for motor competence development, perceived motor competence, and fitness. This spirals into healthy (or unhealthy) weight (top and bottom arrows, right), and feeds back into the model, influencing motor competence and further levels of physical activity (dotted lines, top and bottom). Reprinted by permission of Taylor & Francis LLC (www.tandfonline.com)

Thus, according to this literature, early childhood and adolescence may both be crucial stages of development for physical activity later in life, for different reasons. Early childhood may be a crucial stage because fundamental movement skills are learned at that stage, and adolescence may also be a crucial stage because fundamental movement skills are usually refined into specialized movement sequences at that stage. Partial validation for Stodden et al.'s (2008) developmental model of physical activity comes from a systematic review of fundamental movement skills in children and adolescents (Lubans et al., 2010). In their review, Lubans et al. (2010) found "strong evidence" for a positive association between fundamental movement skills competency and physical activity. They also found fundamental movement skills competency was directly associated with cardiorespiratory fitness, and an inversely associated with overweight (Lubans et al., 2010).

Stodden et al.'s (2008) developmental model of physical activity thus provides theoretical support for the hypothesis that socioeconomic position during childhood has a long-lasting, life course association with physical activity during adulthood. Indeed, we can hypothesize that youth from low socioeconomic position families are less physically active and that they get fewer opportunities to master fundamental movement skills, therefore entering a negative feedback loop involving low motor competency, low perceived motor competency, poor health related fitness, overweight, and progressively lower levels of physical activity. Fundamental movement skills thus become the mechanism through which socioeconomic position during childhood may influence physical activity during adulthood.

In support of this hypothesis, there is some evidence that children from low socioeconomic position families lack mastery of fundamental movement skills (Goodway et al., 2013). There is also evidence that motor development at age 6-9 years is associated with physical activity at age 8-11 years (Vandorpe et al., 2012; Lopes et al., 2011).

Goodway et al. (2013) studied motor skill development in disadvantaged preschoolers. Participants were members of two urban preschools enrolled in compensatory programs serving children at risk of developmental delays (n=469). In school 1 (n=275), children were aged 54.80 months on average (4.57 years) and 96% were African American. The most common risk factors were: single-headed household, low family income, and an unemployed parent who had low educational achievement. All children met federal guidelines for poverty to qualify for the free/reduced lunch program at this preschool. In school 2 (n=190), children were aged 56.37 months on average (4.70 years) and 95% were Hispanic. The same common risk factors were found; in addition, English was a second language for 67% of the children. Overall, 90% met federal guidelines for poverty. The Test of Gross Motor Development-2nd (TGMD-2), a validated instrument to measure fundamental movement skills (Ulrich, 2000), was administered to all children. This test compared the children's performance of a motor skill to a standard, predetermined, desirable performance. This test also provided norm and criterion-referenced information on two subscales: the locomotor subscale and the object control subscale. The locomotor subscale comprised six skills (run, jump, hop, leap, slide, and gallop). The object control subscale also comprised six skills (throw, catch, kick, strike, dribble, and roll). Children's scores in both subscales ranged from 0 to 48 points. Percentile ranks were calculated from raw scores based on children's age and gender. Percentile ranks were then compared to normative data for the TGMD-2, which was in line with U.S. census data by gender, residency, and geographic region (Ulrich, 2000). In school 1, 88% of children were developmentally delayed in locomotor skills and 85% were delayed in object control skills (a developmental delay was defined as scoring below the 30th percentile of normative data for that skill). In school 2, 91% of children were delayed in locomotor skills and 84% were delayed in object control skills. The authors concluded that: "The findings from this investigation show that most children in the two populations served by compensatory preschool programs demonstrated developmental delays in locomotor and object control skills."

Vandorpe et al. (2012) studied motor coordination and sports participation in Flemish children. Children were aged 6-9 years at baseline. They were followed up for two years, until age 8-11 years. A validated test was used to asses children's motor coordination at baseline (the KörperkoordinationsTest für Kinder test). A questionnaire (also validated) was used to obtain information about children's participation in organized sports two years later. A total of 301 children with no missing data were included in the statistical analysis. Logistic regression showed that both motor coordination and sports participation at baseline were significant predictors of sports participation two years later (both $p < 0.001$). According to the authors: "the higher the [motor coordination] values at initial testing, the more likely it is that a child will participate in sports two years later." These results suggest that motor coordination at age 6-9 years influences participation in physical activity at age 8-11 years.

Similar results were obtained by Lopes et al. (2011). In this study, 285 children from the Azores Islands (Portugal) were followed up annually from age 6 to 10 years. Motor coordination was measured using a validated test (the KörperkoordinationsTest für Kinder test). Participation in physical activity was also assessed using a validated questionnaire (the Godin-Shephard questionnaire). Overall physical activity levels declined over time. However, using hierarchical linear modeling, the authors found that "the general trend for a decrease in physical activity level across years was attenuated or amplified depending on initial level of motor coordination," with the decline in physical activity being negligible for children with high levels of motor coordination at age 6 years. In other words, only children with high levels of motor coordination at age 6 years maintained their physical activity levels through age 10 years.

In summary, the literature on fundamental movement skills provides theoretical support for a life course association between socioeconomic position during childhood and physical activity during adulthood. Indeed, based Stodden's developmental model of physical activity participation, we can hypothesize that youth from low socioeconomic position families are less physically active and that they get fewer opportunities to master fundamental movement skills, therefore entering a negative feedback loop involving low motor competency, low perceived motor competency, poor health related fitness, overweight, and progressively lower levels of physical activity. This hypothesis is supported by data showing that children from low socioeconomic position families lack mastery of fundamental movement skills (Goodway et al., 2013). It is also supported by data showing that children with low motor competency at age 6-9 years are less likely to be physically active at age 8-11 years (Vandorpe et al., 2012; Lopes et al., 2011).

3.9 — Physical activity guidelines and recommendations for health

In public health, physical activity is usually defined as "bodily movement produced by the contraction of skeletal muscle that increases energy expenditure above the basal level" (U.S. Office of the Surgeon General, 1996).

In Canada, the Canadian Society for Exercise Physiology recommends that adults "should accumulate at least 150 minutes of moderate- to vigorous-intensity aerobic physical activity per week, in bouts of 10 minutes or more" (Canadian Society for Exercise Physiology, 2011). These are the more recent guidelines. They were published in 2011, following the publication in 2010 of an updated systematic review of the evidence (Warburton et al., 2010).

In the United States, the Department of Health and Human Services recommends that: "adults should do at least 150 minutes (2 hours and 30 minutes) a week of moderate-intensity, or 75 minutes (1 hour and 15 minutes) a week of vigorous-intensity aerobic physical activity, or an equivalent combination of moderate- and vigorous-intensity aerobic activity. Aerobic activity should be performed in episodes of at least 10 minutes, and preferably, it should be spread throughout the week." (U.S. Department of Health and Human Services, 2008).

In both Canada and the US, "moderate- to vigorous-intensity" aerobic physical activity is recommended (Canadian Society for Exercise Physiology, 2011; U.S. Department of Health and Human Services, 2008). Aerobic physical activities can be simply defined as activities that "causes a person's heart to beat faster than usual" (U.S. Department of Health and Human Services, 2008). Moderate-intensity aerobic physical activities include "brisk walking, bicycling, vacuuming, gardening, or anything else that causes small increases in breathing or heart rate" (Physical Activity Guidelines Advisory Committee, 2008). Vigorous-intensity aerobic physical activities include "running, aerobics, heavy yard work, or anything else that causes large increases in breathing or heart rate" (Physical Activity Guidelines Advisory Committee, 2008). Thus, walking briskly at 3.0 miles per hour (4.83 km/h) is considered a moderate-intensity activity and running at 6.0 miles per hour (9.66 km/h) is considered a vigorous-intensity activity (U.S. Department of Health and Human Services., 2008).

The Canadian and the US guidelines are essentially the same. Guidelines in both countries mention that adults should perform "at least 150 minutes of moderate-intensity aerobic physical activity" and that this activity can be accumulated "in episodes of at least 10 minutes." The US guideline is more specific regarding vigorous-intensity activity ("or 75 minutes [1 hour and 15 minutes] a week of vigorous-intensity aerobic physical activity"), although this might make it less clear and harder to remember for the general population (Haskell et al., 2007).

Another important source of physical activity guidelines is the American College of Sports Medicine (ACSM). Although the ACSM is not an official US governmental body, its guidelines enjoy wide support and recognition. Its latest, 2007 physical activity guidelines (Haskell et al., 2007), published jointly with the American Heart Association (AHA), has been cited 2,521 times according to Web of Science and 4,811 times according to Google Scholar (count updated August 14, 2014). The ACSM/AHA recommendation is as follows: "To promote and maintain health, all healthy adults aged 18 to 65 yr need moderate-intensity aerobic (endurance) physical activity for a minimum of 30 min on five days each week or vigorous-intensity aerobic physical activity for a minimum of 20 min on three days each week." (Haskell et al., 2007). These guidelines are more in line with the seminal 1996 report by the US Surgeon General, which stated that: "All people over the age of 2 years should accumulate at least 30 minutes of endurance-type physical activity, of at least moderate intensity, on most—preferably all—days of the week." (U.S. Department of Health and Human Services, 1996).

There is a subtle yet important difference between the Canada/USA guidelines and the ACSM/AHA guidelines. The main difference is that the ACSM/AHA recommends at least 30 minutes of moderate-intensity physical activity on five days each week, whereas the Canada/USA guidelines recommend at least 150 minutes a week. Both amounts are equivalent (30 minutes on five days is 150 minutes), but the distribution may be very different. For example, an individual might perform 150 minutes of biking on Sunday. This individual would meet the Canada/USA guidelines, but not the ACSM/AHA guidelines.

The 1996 US Surgeon General guideline (30 minutes a day) (U.S. Department of Health and Human Services, 1996) was the gold standard for many years and it has influenced much of research in physical activity and health. This criterion has traditionally been used to cut off subjects into physically "active" and "inactive" groups (e.g. Cameron et al., 2007). In this thesis, unless otherwise noted, we will also refer to this criterion to distinguish between physically active and inactive people.

3.10 — Measurement of socioeconomic position in public health research

A variety of terms have been used in public health research to describe socioeconomic status. These include (but are not restricted to): social class, social stratification, social status, socioeconomic position, and socioeconomic conditions. According to Krieger et al. (1997), Lynch and Kaplan (2000) and Galobardes et al. (2006a; 2006b; 2007), "socioeconomic position" is the most generic term. It encompasses concepts with different theoretical, historical and disciplinary origins. In their review, Krieger et al. (1997) first recommended the use of the term "socioeconomic position" over "socioeconomic status" in public health research. They argued that socioeconomic status "blurs distinctions between two different aspects of socioeconomic position: (a) actual resources, and (b) status, meaning prestige- or rank-related characteristics" (Krieger et al., 1997).

Social class (based on occupation) is a common indicator of socioeconomic position, especially in the UK. According to Lynch and Kaplan (2000), social class holds its theoretical basis in the work of Karl Marx (1894). Karl Marx defined social class based on people's relationship with means of production. A purely Marxian view would dichotomize individuals into high or low social class based on their control over means of production (Lynch and Kaplan, 2000).

According to Marx, those in control of the means of production ("owners") exploit those lacking this control ("workers"). In a capitalist society, commodities are produced (by workers) not only to meet their basic needs (and those of owners), but also to produce a surplus. This surplus can then be exchanged in the marketplace. According to Marx, owners, who control the production of commodities and its surplus, stand in exploitative relations to those who produce the surplus, as owners can dispose of it as they see fit to further their own social advancement. Thus, according to Marx, social classes are inherently opposed and in conflict. Marx's view is structural: social class is imposed by control over (privately-held) means of production, which are exogenous to the individual.

The work of Max Weber (1922) offers another theoretical basis for socioeconomic position in public health research. In contrast with Marx, Weber places more emphasis on human agency. In his view, socioeconomic position is not entirely exogenously determined and individuals can further their own social advancement through means outside of working relations. Weber recognized that dynamics of control over means of production mattered, but not because of exploitative relations; rather, because they shaped the distribution of opportunities, knowledge, assets, and skills. Weber proposed that society is hierarchically stratified along multiple dimensions (and not only social class). Weber conceived of individuals sharing a common set of circumstances, beliefs, and values, as a group with similar "life chances." In contrast with Marx's view, for Weber, individuals have a greater degree of control over their fate (or life chances). They can trade their education, skills, and attributes in the marketplace to further their social advancement. Thus, Weber's view accommodates greater agency and forms the theoretical basis for using multiple indicators of socioeconomic position, such as education, income, and occupation (Lynch and Kaplan, 2000).

A new, multi-dimensional model of social class has been developed in the UK (Savage et al., 2013) based on the work of French sociologist Bourdieu. According to Bourdieu (1984), class is a complex interplay of economic, social, and cultural capital, each conveying distinct advantages. This complex interplay is embodied in the individual as the habitus, referring to a "system of acquired dispositions functioning on the practical level as categories of perception and assessment or as classificatory principles as well as being the organizing principles of action" (Bourdieu, 1990; p. 13). More simply, habitus refers to "the physical embodiment of cultural capital, to the deeply ingrained habits, skills, and dispositions that we possess due to our life experiences" (Longhofer and Winchester, 2012). Thus social class, through the habitus, shape an individual's habits, identity, and dispositions towards physical activity and leisure (Dagkas and Stathi, 2007). In turn, preferences in physical activity contribute to social reproduction and cultural distinction, which are key concepts in Bourdieu's conceptualization of social class (Savage et al., 2005).

In his paper Sport and social class, Bourdieu (1978) noted that the distribution of sporting practices across social classes must take account of spare time, economic capital, and cultural capital. He further noted that "what is most essential" is "the variations in the meaning and function of the different sports among the social classes." He argues that "the different social classes do not agree as to the effects expected" of exercise on the body. Some prefer bulging muscles, while others prefer ease and elegance. In other words, variations in sporting preference by social class depend not only on economic and cultural costs, but also on "variations in the perception and appreciation of the immediate or deferred profits accruing" from sport practice. Moreover, class habitus "defines the social value accruing from the pursuit of certain sports by virtue of the distinctive rarity they derive from their class distribution." Thus, according to Bourdieu, sports are not only pursued for their intrinsic value (i.e. for health), but also to further one's social capital. Bourdieu cites weightlifting, "the favourite working-class sport," as an example of a sport with low social value. Indeed, while the first modern Olympic Games were held in 1896, the "aristocratic founder of modern sport" only granted it official recognition much later. It became an Olympic event in its own right only 24 years later, in 1920 (Olympic Movement, 2015). In contrast, Bourdieu gives the example of golf, shooting, and polo in smart clubs, where sporting activity becomes "a mere pretext for select encounters [...] a technique of sociability." In summary, Bourdieu places cultural capital at the core of its sociological analysis of sporting and physical activity, with economic capital having a secondary role. This provides another theoretical basis for using multiple indicators of socioeconomic position, including income, and, above all, education.

Also relevant to our study of socioeconomic position, physical activity, and health is the theory of fundamental causes (Link and Phelan, 1995). This theory aimed to explain why the association between socioeconomic position and mortality has persisted despite radical changes in fatal diseases and corresponding risk factors (Phelan et al., 2010). The authors give the example of the transition from infectious to chronic diseases. In the past, infectious diseases such as typhoid fever and tuberculosis were more common in low socioeconomic homes and communities, because of crowding and poor sanitation. In modern times, chronic diseases such as cancer and cardiovascular disease are more common in low socioeconomic groups because of poor diet, low physical activity, and high smoking. As the authors have shown, fatal diseases and their risk factors have changed, but their unequal distribution remains, with those at the bottom of the social hierarchy suffering a disproportionate share. According to Phelan et al. (2010), social inequalities in health endure because socioeconomic position "embodies an array of resources, such as money, knowledge, prestige, power, and beneficial social connections that protect health no matter what mechanisms are relevant at any given time."

Based on this theory, Phelan et al. (2004) hypothesized that social inequalities would be wider for diseases for which methods of prevention or treatment are known, whereas inequalities would be less pronounced for diseases for which methods of prevention and treatment are not known. Their hypothesis was confirmed, as socioeconomic inequalities in mortality were significantly more pronounced for causes of death that were reliably rated by two physician-epidemiologist as being highly preventable (such as lung cancer and ischemic heart disease) than for causes that were rated as not very preventable (such as brain cancer and arrhythmias) (Phelan et al., 2004). Similar results were also found when comparing causes of death for which great strides in prevention or treatment were made with causes of death for which less progress had been made over the same period (Phelan and Link, 2005). These results and others (Tehranifar et al., 2009) provided empirical support for the theory of fundamental cause.

Because different theoretical backgrounds underpin many of the indicators used in public health research, a consensus is seemingly forming around the use of the term "socioeconomic position" as more general and encompassing (Krieger et al., 1997; Lynch and Kaplan, 2000; Regidor, 2006; Galobardes et al., 2006; Galobardes et al., 2007). Theory notwithstanding, many researchers agree it is an aggregate concept that is, in practice, most often operationalized using education, income, and occupation (Krieger et al., 1997; Regidor, 2006; Galobardes et al., 2006; Galobardes et al., 2007). The correlation between these three indicators in developed countries is low to moderate (0.3-0.6) (Liberatos et al., 1988; Abramson et al., 1982; Winkleby et al., 1990; Geronimus and Bound, 1998). This suggests that each indicator measures a slightly different dimension of socioeconomic position (Galobardes et al., 2001; Regidor, 2006; Galobardes et al., 2006). In turn, each dimension is likely to influence health and health behaviours through different pathways (Macintyre et al., 2003; Regidor, 2006; Geyer et al., 2006). In our own research, we have used the term "socioeconomic position" in a broad sense to refer to the social distributions of occupations, income, wealth, education, and social status (Krieger et al., 1997).

3.11 — Measurement of physical activity in public health research

3.11.1 — Validity and reliability of instruments commonly used to measure physical activity

We have noted previously that physical activity is defined as "bodily movement produced by the contraction of skeletal muscle that increases energy expenditure above the basal level" (U.S. Office of the Surgeon General, 1996). The gold standard measure of energy expenditure (and physical activity) is direct calorimetry (Pettee et al., 2009). Direct calorimetry is the measurement of body heat production. It is carried out in the laboratory, with the subject in an airtight, temperature-controlled chamber. The temperature of the chamber is carefully monitored and any elevation of its temperature is attributed to the heat produced by the subject's body. Body heat production is a measure of energy expenditure because energy metabolism generates heat (this was recognized by Lavoisier more than 230 years ago) (Shephard and Aoyagi, 2012). Thus, when muscles contract, heat is produced. The amount of heat produced is directly proportional to the energy expended by the subject. The more strenuous the physical activity, the more energy the subject expends, and the more body heat is produced (this is why heavy exercise increases body temperature and causes sweat). Therefore, by measuring body heat production by direct calorimetry, researchers can measure the energy expenditure of physical activity. Because measurement is carried out in an airtight chamber, this methods limits the range of physical activities that can be performed and studied. It is, however, the most precise measure of energy expenditure (in a review, estimates of 1-2% error have been reported) (Levine, 2005). Therefore, all measures of physical activity should ultimately be validated against direct calorimetry.

Indirect calorimetry is a more convenient, albeit slightly less precise measure of energy expenditure that is also often used as a criterion measure in validity assessment. Its main strength is that it can be carried out in the field, during task-specific activities. During indirect calorimetry, the subject breathes in and out of a mask or fitted mouthpiece. The mouthpiece is linked to a portable airbag or metabolic cart. Air flow is carefully monitored, and concentrations of oxygen (O_2) and carbon dioxide (CO_2) are measured in the air as it enters and leave the subject's body. O_2 is used by the body to extract energy from lipids, carbohydrates, and proteins found in body energy stores and in food. As the body extracts energy from lipids, carbohydrates, and proteins to fuel physical activities, CO_2 is produced. Thus, by measuring differences in O_2 and CO_2 concentrations in the air as the subject breathes in and out, researchers can estimate how much energy was extracted and expended from lipids, carbohydrates, and proteins. In a review, Levine (2005) reported estimates of 0.5-3% error for indirect calorimetry. Indirect calorimetry is less restrictive than direct calorimetry, but it still requires a specialized technician and cumbersome, carefully calibrated instruments to analyze O_2 uptake and CO_2 production. Therefore, it cannot be used in free-living populations to monitor spontaneous, habitual physical activity over days, weeks, or months.

Of all the measures used today in free-living populations, only two have shown high validity: doubly labeled water and accelerometers. Doubly labeled water ($^2H_2{}^{18}O$) is water (H_2O) that has been "labeled" with stable isotopes[1] of hydrogen (^2H) and oxygen (^{18}O). Hydrogen and oxygen, the two elements that compose water, have been labeled, hence the name "doubly labeled water." To measure physical activity using this method, the subject drinks a predetermined quantity of doubly labeled water. Over the next several hours, the doubly labeled water diffuses in the subject's body. This is the "equilibration period," during which the labeled hydrogen and oxygen mix with the subject's natural body water space. After this period, urine, saliva, or blood is collected and the initial concentrations of labeled hydrogen and oxygen in the subject's body water are measured. The subject then leaves the laboratory and is free to engage in daily activities for a period lasting usually 14 or 21 days. After this period, the subject returns to the laboratory to have his urine, saliva, or blood collected again. Body water concentrations of labeled hydrogen and oxygen are measured in this second and final sample. Then, body water concentrations of labeled hydrogen and oxygen in the first (initial) and second (final) sample are compared to estimate energy expenditure.

[1] Isotopes are atoms of the same element that differ in atomic mass because they have extra (or fewer) neutrons in their nuclei. Stable isotopes (such as ^2H_2O and $H_2{}^{18}O$, used in doubly labeled water) have specific combinations of neutrons and protons that are stable. Other isotopes (such as ^{14}C) have too many (or too few) neutrons and are unstable and radioactive.

Energy expenditure can be estimated because while oxygen and hydrogen turnover in the body are determined by the flow of water, oxygen turnover is determined as well by inspired oxygen and expired carbon dioxide (while hydrogen turnover is not). Consequently, the difference between the turnovers of oxygen and hydrogen provides a measure of the excess efflux of oxygen that is equivalent to the production of carbon dioxide by energy metabolism; this is the fundamental basis of the doubly labeled water method (Speakman, 1998). Because some time must be allowed between the first and the second urine, saliva, or blood sample, the doubly labeled water method can only be used to examine medium- to long-term averages of accumulated total, whole-day physical activity (Shephard and Aoyagi, 2012). This is both a strength and a limitation.

It is a strength because the subject is free to carry out his habitual daily activities; therefore, the doubly labeled water method truly measures unrestricted, free-living physical activity. But it is also a limitation because the doubly labeled water method gives no indication of the type, frequency, intensity, and duration of physical activities performed. Neither does it inform about the domain of life during which the subject is active (at work, during leisure, or for transportation). To illustrate, picture a white collar employee who spends most of his week days seated at his office desk, but who runs a marathon every weekend. Let us compare that white collar employee to a blue collar operator of heavy machinery who spends all his free time on the couch, watching TV. After a 14-day doubly labeled water measurement, it is conceivable that both would have expended similar quantities of energy in physical activity; although their pattern of activity are at opposed extremes in terms of type, frequency, intensity, and duration (the white collar employee would have high levels of physical activity during leisure time and low levels of physical activity at work; the opposite would be true for the blue collar employee). Another limitation of doubly labeled water is its high cost ($700 / subject) (Levine, 2005). This, coupled with the added expense of specialized equipment (mass spectrometer) and staff for measuring labeled hydrogen and oxygen concentrations, make doubly labeled water cost-prohibitive for large-sample epidemiological studies.

In a review, Speakman (1998) reported both underestimation (up to 3.1%) and overestimation (up to 3.3%) of energy expenditure by doubly labeled water when validated against indirect calorimetry. A more recent validation study found doubly labeled water overestimated energy expenditure by 1.3% (de Jonge et al., 2007) when compared to indirect calorimetry. Consequently, doubly labeled water is generally considered a valid method for measuring energy expenditure and physical activity. Since its first application to human subjects in 1982 (Schoeller and van Santen, 1982), it has become the gold standard for measurement of habitual, free-living physical activity (Westerterp and Plasqui, 2004, Shephard and Aoyagi, 2012).

The other reasonably valid method of measuring physical activity in free-living populations is accelerometers. Accelerometers are devices that measure acceleration. Modern accelerometers detect acceleration in three directions and are called "tri-axial accelerometers." They are more valid than previous models that detected acceleration in only one direction ("uni-axial accelerometers"). Thanks to rapid technological advancement, modern, current-generation accelerometers weigh about 100 grams, have enough battery life to measure physical activity continuously for up to 3 weeks, and are usually worn at the wrist (most models resemble a watch) (Plasqui et al., 2013). In contrast with the doubly labeled water method, accelerometers give a picture of the total amount, intensity, duration, and frequency of physical activity. Some models also measure the gravitational field (using a piezo-resistive sensor). This allows to determine the orientation of the body and body posture, and these models can detect rough patterns of movement and provide information about up to six activity types (lying, sitting/standing, active standing, walking, running and cycling) (Plasqui et al., 2013). This feature is still in development, however, and to our knowledge, no accelerometer study has yet reported a complete, accurate description of minute-by-minute, 24-hour, free-living physical activity by physical activity type for any length of time. Accelerometers hold much promise because of these developments and may, one day, be the gold standard method for measuring free-living physical activity.

Van Remoortel et al. (2012) systematically reviewed the literature on accelerometers validity. A total of 134 papers testing 40 different accelerometers met their inclusion criteria. Of those, 40 validated accelerometers on the field (against doubly labeled water), 86 carried out validation in the laboratory (against indirect calorimetry), and 8 used both approaches. A total of 118 studies had been performed in healthy adults, with 16 carried out in patients with chronic diseases. For field studies, a pooled correlation coefficient of 0.59 (95%CI, 0.45 to 0.70) was found between tri-axial accelerometers and doubly labeled water for physical activity-related energy expenditure. Tri-axial accelerometers underestimated physical activity-related energy expenditure measured by doubly labeled water by 21.01% (95%CI, -41.92 to -0.11). For laboratory studies, a pooled correlation coefficient of 0.84 (95%CI, 0.78 to 0.89) was found between tri-axial accelerometers and indirect calorimetry for total energy expenditure during walking or simulated daily living activities. The authors reported under- or overestimation data for walking and running only. Those ranged from -15% to +47.09%. The pooled correlation coefficient for validation against indirect calorimetry (0.84, 95%CI: 0.78 to 0.89) was higher than the pooled correlation coefficient for validation against doubly labeled water (0.59, 95%CI, 0.45 to 0.70). This may be explained by the nature of the activities performed during each type of validation study. For indirect calorimetry studies, short-duration, task-specific energy expenditure was measured. For doubly labeled water validation studies, free-living activity over multiple days was measured. Thus, the shorter duration of physical activity tasks during validation may explain why validity was higher in laboratory studies.

Overall, these results suggest accelerometers are a reasonably valid measure of physical activity, even more so for short duration, task-specific activities. Doubly labeled water and accelerometers share a common limitation: they are too costly to be used in large sample epidemiological studies.

Questionnaires have thus far commonly been used to measure physical activity in epidemiological studies. There are two benefits of using questionnaires. First, they are less costly than accelerometers and doubly labeled water. Second, they can be used to recall past physical activity (this cannot be done with accelerometers or doubly labeled water). However, questionnaires have a major drawback. Even when validated, questionnaires are prone to significant measurement error (Prince et al., 2008; Lee et al., 2011).

In a systematic review, Prince et al. (2008) searched for studies that examined agreement between self-reported and objectively measured physical activity in adults. Instruments based on self-reports included questionnaires and diary. Objective measures included accelerometers, doubly labeled water, indirect calorimetry, heart rate monitors, and pedometers. They identified 4,463 studies; 187 were included for data extraction. Only 148 studies reported correlation statistics between self-reported and objectively measured physical activity. Estimates of physical activity based on self-reports were both higher and lower than directly measured levels. Correlations were low-to-moderate with a mean of 0.37 (SD = 0.25) and a range of -0.71 to 0.98. Additional analyses were carried out in a subsample of 74 studies containing comparable data. In 60% of these studies, estimates based on self-reports of physical activity were higher than those based on objective measurement. In 40% of them, they estimates based on self-reports of physical activity were lower than those based on objective measurement. This pattern differed by objective measure used for validation. When compared to accelerometers, self-reports overestimated physical activity (mean percent difference for studies reporting on combined male and female data: +44%). When compared to doubly labeled water, self-reports underestimated physical activity (mean percent difference for studies reporting on combined male and female data: -9%).

When compared to heart rate monitors, women tended to over-report physical activity (mean difference: +11%), while men tended to under-report it (mean difference: -9%). For pedometers, self-reports were higher than objective measures in seven out of eight comparisons. Indirect calorimetry results "were less straightforward and presented no obvious patterns in agreement." (Prince et al., 2008). Overall, these results indicate that studies relying on self-reports of physical activity may present substantial misclassification bias.

In another systematic review, Lee et al. (2011) searched for validation studies of the International Physical Activity Questionnaire (short form), the IPAQ-SF. The IPAQ was developed in 1998 by a group of experts. It has since become the most widely used questionnaire to measure physical activity. A total of 61 unique validation papers were found for the IPAQ. Only 23 remained after exclusion (13 papers focused on the long form of the IPAQ, 11 papers validated other measures against the IPAQ, five were not in English, three validated a modified version of the IPAQ, three were applications of the IPAQ, one reviewed properties of physical activity questionnaires among the elderly, one was a comment article, and one was a qualitative study translating the IPAQ-SF). Results for 18 correlations of IPAQ "total activity level" with objective measuring devices (accelerometers, pedometers, and actometers) shows 16 of them were small and two were negligible (range of Spearman's rho = 0.09 to 0.39, median = 0.29). Correlations between IPAQ-SF total activity level and fitness measures (VO2max, maximum treadmill time, and 6-minute walk test) were small in four out of five studies (range of Spearman's rho = 0.16 to 0.36, median = 0.30). Only one study validated the IPAQ against doubly labeled water. It concluded that highly active participants could be correctly identified and distinguished from inactive participants using the IPAQ, but discrimination between moderately active and inactive participants was poor. Only six studies reported on the amount of physical activity (in MET-min per week) measured by the IPAQ-SF and objective (accelerometer) data. In one study, the IPAQ under-reported physical activity by -28%. In the other five studies, physical activity was over-reported by an average of 106% (range: 36% to 173%). Overall, these findings indicate that even validated questionnaires are prone to substantial measurement error.

Moreover, the criterion measure of physical activity often used to validate physical activity questionnaire (accelerometers) is in itself prone to measurement error, as we have seen (Van Remoortel et al., 2012). Thus, care should be used when interpreting questionnaire-based physical activity data from large-scale epidemiological studies, even when validated questionnaire are used. We have highlighted this limitation in our own research.

3.11.2 — The four domains of physical activity

Physical activity can be measured in four domains of life: during leisure time, at work, at home, and during transports (Bauman et al., 2006).

The first domain of physical activity is leisure-time physical activity. it includes organized activity such as team or individual sport, walking groups, and gym classes. It also includes non organized, recreational sport and walking for exercise (Bauman et al., 2006).

The second domain of physical activity is physical activity at work (or "occupational physical activity"). It includes all work-related energy expenditure (Bauman et al., 2006).

The third domain of physical activity is physical activity at home (also sometimes called "housework" or "domestic" physical activity). It includes do-it-yourself repairs, gardening, house cleaning, and child care (Lawlor et al., 2002; Bauman et al., 2006).

The fourth domain of physical activity is physical activity during transports. It include all forms of physically active transportation, such as walking and cycling, to get to and from places (Bauman et al., 2006).

Physical activity in all four of these domains of life has the potential to enhance health and to prevent premature mortality (Samitz et al., 2011). Indeed, one of the very first studies linking physical activity to health was carried out in a work setting (Morris et al., 1953). More recently, Samitz et al. (2011) conducted a systematic review and meta-analysis to determine the association with all-cause mortality of different domains of physical activity. Data from 80 studies with 1,338,143 participants was used to estimate combined risk ratios using random-effects models. Combined risk ratios comparing highest with lowest physical activity levels were 0.65 (95% CI 0.60–0.71) for total physical activity, 0.74 (95% CI 0.70–0.77) for leisure-time physical activity, 0.64 (95% CI 0.55–0.75) for activities of daily living (including housework and gardening), 0.88 (95% CI 0.79-0.98) for physical activity during transports, and 0.83 (95% CI 0.71–0.97) for occupational physical activity. The authors concluded that "Higher levels of total and domain-specific physical activity were associated with reduced all-cause mortality" (Samitz et al., 2011). Thus, physical activity in all domains of life can prevent premature mortality, and not just physical activity during leisure time.

Traditionally, public health guidelines have focused on exercise, promoting increased physical activity during leisure time (ACSM, 1978; ACSM 1990; U.S. Office of the Surgeon General, 1996; Blair et al., 2004). More recent guidelines encourage people to be active in all domains of life, and not just during their leisure time (U.S. Office of the Surgeon General, 1996; Haskell et al., 2007; U.S. Department of Health and Human Services, 2008; World Health Organization, 2010; Canadian Society for Exercise Physiology, 2011). For example, the latest Canadian guidelines (150 minutes a week) mention that "Adults can meet these guidelines through planned exercise sessions, transportation, recreation, sports, or occupational demands, in the context of family, work, volunteer, and community activities (Canadian Society for Exercise Physiology, 2011).

In our own research, whenever available, we have used measures of physical activity for multiple domains of life. When only leisure-time physical activity was measured, we have underscored this limitation.

SECTION 4 — METHODS

4.1 — Study design

This thesis comprised three studies. A systematic review and two studies with original research. "Gold standard" guidelines for systematic reviews in medical research have been issued by the Cochrane Collaboration (Higgins and Green, 2011). These guidelines were crafted for intervention trials. They were thus not entirely relevant to the literature we reviewed, as it consisted of observational studies only. Therefore, when appropriate, we followed the guidelines for systematic review and meta-analysis of observational studies in epidemiology proposed by Stroup et al. (2000). Pai et al. (2004) was used as a supplemental source of guidelines. The full methods for our systematic review are described in section 5.

Study design for our two original research was similar for both studies. We used data from two large, ongoing, prospective, nationally representative cohorts: the 1970 British birth cohort (UK data) and the National Longitudinal Survey of Children and Youth (Canadian data). In both datasets, we used structural equation modeling to examine the association between socioeconomic position during childhood and physical activity during adulthood from a life course perspective. Socioeconomic position was assessed using social class in the UK dataset. In the Canadian dataset, it was assessed using education and income. Physical activity during adulthood was self-reported by questionnaire in both datasets. Information about physical activity during leisure time, during transports, and at work was available in the UK dataset. In the Canadian dataset, only physical activity during leisure time was measured. Full methods for both studies are described in section 5.

4.2 — Data

4.2.1 — Dataset 1: The 1970 British birth cohort (UK)

The first source of data is the 1970 British birth cohort (Elliott and Shepherd, 2006). This prospective birth cohort originally included all babies born the same week in April 1970 in England, Scotland, Wales, and Northern Ireland (16,571 participants). Its first aim was to examine the social and biological characteristics of the mother in relation to neonatal morbidity, but it later expanded into an ongoing, multidisciplinary study. To date, there have been over 300 publications based on this cohort. These examined perinatal antecedents of health problems, social inequalities and health, and health-related behaviours, among others. Data were collected at birth and participants were followed up six times, at ages 5, 10, 16, 26, 30, and 34 year. Sample size at each follow-up were, respectively, 13,071 (78.88%), 14,874 (89.76%), 11,621 (70.13%), 9,003 (54.33%), 11,261 (67.96%), and 9,656 (55.86%). Participants born in Northern Ireland were not followed up and were excluded from the study. Up until age 16 years, immigrants traced in schools and born in the reference week were added to the sample. In 1970, data were collected using a questionnaire completed by the midwife who had been present at birth. Information was also extracted from clinical records. In 1975 and 1980, at ages 5 and 10 years, participants' parents were interviewed, and information was gathered from the children themselves, their school teachers, and the school health service. In 1999/2000, subjects (now aged 30) answered questions about all major domains of life during a follow-up telephone interview. In 2004/2005 subjects (now aged 34) also answered questions about all major domains of life during a telephone interview (Elliott and Shepherd, 2006).

4.2.2 — Dataset 2: The National Longitudinal Survey of Children and Youth (Canada)

The second source of data is the National Longitudinal Survey of Children and Youth (NLSCY) (Statistics Canada, 2008). This longitudinal survey aimed to monitor the development and well-being of a representative sample of Canadian children. Its primary objective was to develop a national database of the characteristics and life experiences of Canadian children as they grew from infancy to adulthood. Data collection for this nationally representative prospective cohort began in 1994. Subjects were a random sample of all Canadian children aged 0-11, excluding those living in institutions or on Indian Reserves. Sampling covered approximately 99.5% of children living in the 10 Canadian provinces. Data were collected in 1994, 1996, 1998, 2000, 2002, 2004, 2006, and 2008 by trained interviewers employed by Statistics Canada. Interviews were assisted by computer and carried out over the telephone or, for about 40% of the sample, face-to-face. Data collection began in 1994 with one large cohort of 16,903 children aged 0-11. For this research projects, the analysis focused on a subsample of 1,243 children. The 1,243 children in this subsample were aged 8-9 in 1994 and 22-23 in 2008. It was necessary to focus on this subsample because our outcome (leisure-time physical activity) was measured in these subjects only. Indeed, only subjects aged 22-23 were asked about their leisure-time physical activity in 2008 (Statistics Canada, 2008).

4.2.3 — Limitation of secondary analysis of existing databases

As we have just seen, we have carried out secondary analysis of two preexisting datasets. These datasets were: (1) the 1970 British birth cohort and (2) the National Longitudinal Survey of Children and Youth. This approach (secondary data analysis) introduces some limitations in our analysis. These limitations are related to: (1) the age of the study participants when data is first collected at the outset of the study, (2) at what age and how frequently data is collected across the life course, (3) the choice of measures of socioeconomic position, and (4) the choice of measures of physical activity. We will expand on these limitations in our discussion, in section 6.

4.3 — Variables and measurement

4.3.1 — Dataset 1: The 1970 British birth cohort (UK)

In the UK data, independent variables were social class at birth and at ages 5, 10, 30, and 34 years. Occupation (a measure of social class) was used to indicate socioeconomic position. It was self-reported by parents during interviews at birth and when subjects were aged 5 and 10 years. Occupation was also self-reported by subjects at ages 30 and 34 years during face-to-face interviews. For birth and ages 5 and 10 years, the highest parent's occupation was used as proxy. Occupations were categorized according to the Registrar General's classification into grades I (professional) to V (unskilled). At all ages, less than 2.6% of cases were from social class V (unskilled). Therefore, social classes IV (partly skilled) and V (unskilled) were merged. As grade III (skilled) is split into manual and nonmanual, occupation was thus a categorical variable with five ordered categories. Although the validity of this measure's theoretical basis has been contested (Szreter, 1984; Galobardes et al., 2006b), it has been widely used in epidemiologic research since its introduction in 1911 (Galobardes et al., 2006b). Indeed, a recent Google Scholar search for "Registrar General" and "epidemiology" has yielded 15,100 results (count last updated: November 3rd, 2015). In our own research, for clarity, we have used the term “social class” to refer to this measure of social class based on occupation.

Dependent variables were physical activity during leisure time, physical activity at work, and physical activity during transports. All were self-reported by subjects during interviews at age 34 years. For physical activity during leisure time and physical activity at work, a score representing eight weeks of habitual physical activity was computed based on answers to three questions (for leisure-time physical activity) and two questions (for physical activity at work). These scores approximated energy expenditure: the higher the score, the more physically active the subjects were and the more energy they expended during leisure time or at work. Both scores were positively skewed and had a mode of 0.

The score for leisure-time physical activity was computed as follows. Subjects were shown a card with a list of common leisure-time physical activities, including competitive sports (any kind), aerobics classes, running or jogging, going for walks, outdoor sports, dancing, and “any other sport or leisure activity which involves physical exercise.” They were then asked: “Do you regularly take part in any of the activities on this card. By regularly I mean at least once a month, for most of the year?” Answers were: “yes” or “no”. Subjects who answered “yes” were then asked: “How often do you take part in any activity of this type?” Answers were: “every day”, “4-5 days a week”, “2-3 days a week”, “once a week", “2-3 times a month”, or “less often.” They were also asked: “And when you take part in any activity of this type, would you say you got out of breath or sweaty...” Answers were: “most times”, “sometimes”, “rarely,” or “never”. A physical activity score representing 8 weeks of habitual physical activity was computed based on these answers. Subjects who did not exercise were given a value of zero. The score for those who exercised was computed by multiplying how often they did so (frequency, over 8 weeks) by how often they got out of breath or sweaty (intensity). For frequency, subjects who exercised “every day” were given a value of 56 (8 weeks multiplied by 7 days a week). Those who exercised “4-5 days a week” were given a value of 36 (8 weeks multiplied by 4.5 days a week). Those who exercised 2-3 days a week were given a value of 20 (8 weeks multiplied by 2.5 days a week). Those who exercised once a week were given a value of 8 (8 weeks multiplied by 1 day a week). Those who exercised 2-3 times a month were given a value of 5 (2.5 days a month multiplied by 2 months [8 weeks was considered two months; this was necessary to obtain only integer values and treat this outcome as a count variable in the models]). Finally, those who exercised “less often” were considered to be exercising once every 4 weeks and were given a value of 2 (8 weeks multiplied by 1 day every 4 weeks). Next, for intensity, all subjects who got out of breath or sweaty “most times” were given a value of 4. Those who got out of breath or sweaty “sometimes” were given a value of 3. Those who got out of breath or sweaty “rarely” were given a value of 2. Finally, those who got out of breath or sweaty “never” were given a value of 1. These two sets of values were multiplied to compute the subjects’ physical activity score. The score took 23 values between 0 (no exercise at all) and 224 (subject exercises "every day" and gets out of breath or sweaty "most times"). This score approximated energy expenditure: the higher the score, the more physically active the subjects were and the more energy they expended through physical activities. The score was not normally distributed, having a range from 0 to 224 with a median of 40 and mode of 0. The score was positively skewed (skewness = 1.103; SE = 0.025; Kolmogorov-Smirnov test of normality with Lilliefors Significance Correction $p < 0.001$). The physical activity score was used at the dependent variable for leisure-time physical activity, and zero-inflated Poisson models were used to account for the large number of zeros and positive skewness.

For score for physical activity at work was computed as follows. Subjects were asked: "Do you use a computer at work?" Answers were: "yes" or "no". Subjects who answered "Yes" were then asked: "How often do you use the computer?" Answers were: "Daily", "2-4 times a week", "Once a week", or "Less than once a week". A score for physical activity at work over 8 weeks was computed based on these answers. Subjects who said they did not use a computer at work were given a value of zero. Subjects who said they used a computer at work were given a value based on how often they said they used it in a week. Subjects who used a computer daily were given a value of 56 (8 weeks multiplied by 7 days a week). Subjects who used a computer 2-4 times a week were given a value of 24 (8 weeks multiplied by 3 days a week, the average of 2 and 4). Subjects who used a computer once a week were given a value of 8 (8 weeks multiplied by 1 day a week). Subjects who used a computer "less than once a week" were considered to be using a computer once every 4 weeks. They were given a value of 2 (8 weeks multiplied by 1 day every 4 weeks). The score for physical activity at work took 5 values between 0 and 56. The higher the score, the more subjects were using a computer at work, indicating less physical activity at work. To facilitate analysis and interpretation, the score was reverse coded, so that the higher the score, the less subjects were using a computer a work, indicating more physical activity at work (higher score, more physical activity at work). The (reverse coded) score could be interpreted as "how many days the participant does not use a computer at work over 8 weeks". The (reverse coded) score was not normally distributed, having a range from 0 to 56 with a median and a mode of 0. The (reverse coded) score was positively skewed (skewness = 0.634; SE = 0.027; Kolmogorov-Smirnov test of normality with Lilliefors Significance Correction $p < 0.001$). This score was used at the dependent variable for physical activity at work, and zero-inflated Poisson models were used to account for the large number of zeros and positive skewness.

Physical activity during transport was based on a single question about main form of transport. Subjects were asked: “What is your main form of transport?” Answers were: “car/motorcycle/moped”, “public transport (i.e. buses and trains)”, “cycling”, “walking”, “other”, or “never goes out”. Public transport was considered an active form of transport. Answers were recoded into “active” (public transport, cycling, or walking), “inactive” (car/motorcycle/moped), or “missing” (other, don't know, never goes out, or not applicable). Therefore, main form of transport was a dichotomous variable (“active” or “inactive”). Sex was a dichotomous variable (“male” or “female”). It was a confounder, and all analyses were stratified by sex. Other confounders (for physical activity during transports only) were "Time required to travel from home to work" (a categorical variable with eight ordered categories ranging from "under 5 minutes" to "2 or more hours") and "Rating of local public transport services" (a categorical variable with five ordered categories ranging from "very good" to "very poor").

4.3.2 — Dataset 2: The National Longitudinal Survey of Children and Youth (Canada)

In the Canadian data, independent variables were education and income. Both were reported by parents when participants were aged 8-9 years (in 1994) and 14-15 years (in 2000). Both were also self-reported by participants at age 22-23 years (in 2008). The highest of the two parents' education was used as proxy for participants' education at ages 8-9 years and 14-15 years. The participants' own self-reported educational attainment was used at age 22-23 years. Self-reports were recoded into years of education: education was a continuous variable. Household reported income was used as proxy for subjects at ages 8-9 years and 14-15 years. Personal income was used at age 22-23 years. Income was an ordinal variable with nine categories.

The dependent variable was leisure-time physical activity. It was self-reported by subjects at age 22-23 years. Subjects were asked: “In the past 12 months, how often have you taken part in sports or done physical activities such as, swimming, aerobics, or some other sport?” Answers were: “never”, “less than once a week”, “1 to 3 times a week”, and “4 or more times a week.” Subjects were then asked: “Thinking of the sport or physical activity you do most often, how long do you usually spend being active in one session?” Answers were: “1 to 15 minutes”, “16 to 30 minutes”, “31 to 59 minutes”, “1 to 2 hours”, and “more than 2 hours”. A new variable was computed based on these two questions. It was equal to activity frequency per week (question 1) multiplied by usual session duration in minutes (question 2). This variable provided an estimate of how many minutes per week subjects spent in leisure-time physical activities over the past 12 months. Weekly minutes of leisure-time physical activity was a continuous variable. It was skewed to the right. To improve its distribution, its square root was used.

4.4 — Statistical methods

In our two original contributions, we have used structural equation modeling to examine the association between socioeconomic position during childhood and physical activity during adulthood from a life course perspective. This statistical technique has three advantages over the traditional, regression-based techniques (such as logistic and multiple regression) which are often used in life course epidemiology to analyze life course data.

First, all associations between any number of variables in the model can be estimated at once. In traditional regression-based techniques (such as multiple regression), only the associations between each predictor variable and the outcome are estimated. Associations between predictors are not estimated, and additional regressions need to be performed to obtain these estimates. This approach is not parsimonious, and it can lead to inflated type 1 error.

Second, indirect associations can be estimated. That is, using structural equation modeling, we can estimate how strongly socioeconomic position during childhood is associated with physical activity during adulthood directly (independently) and also indirectly through socioeconomic position during adulthood. The standard approach to estimating indirect associations in traditional regression-based techniques is to estimate each indirect association separately in a series of regression analyses (Baron and Kenny, 1986). This approach is not parsimonious. Also, it has low statistical power (MacKinnon et al., 2002).

Third, competing models can be compared based on goodness of fit statistics. For each model, structural equation modeling provides fit indices. These indices can be compared across models to determine which model fits the data best. Many fit indices have been developed for structural equation modeling, and their interpretation is well documented (Hu and Bentler, 1999; Tabachnick and Fidell, 2007; Schermelleh-Engel et al., 2003). In addition, for nested models, a formal statistical test of significance exists to determine which model fits the data best. In contrast, estimates of different models obtained using traditional regression-based techniques cannot be formally compared using a statistical test.

We have applied structural equation modeling to life course data on socioeconomic position and physical activity in the UK (dataset 1) and in Canada (dataset 2). In doing so, we have highlighted the benefits of using structural equation modeling over traditional regression-based statistical techniques. These applications are presented in the following section.

SECTION 5 — RESULTS

5.1 — Socioeconomic position during childhood and physical activity during adulthood: a systematic review

There is no clear cross-sectional association between socioeconomic position during childhood and physical activity during childhood (Van Der Horst et al., 2007; Gustafson and Rhodes, 2006). However, there is some evidence that children from low socioeconomic position families lack mastery of fundamental movement skills (Goodway et al., 2013), which are theorized to form the basis for sports participation later in life (Stodden et al., 2008). There is also evidence that motor development at age 6-9 years is associated with physical activity at age 8-11 years (Vandorpe et al., 2012; Lopes et al., 2011), indicating that socioeconomic differences in physical activity levels may not appear until late childhood. By adolescence, there is a cross-sectional association between socioeconomic position and physical activity (Stalsbergs and Pedersen, 2010). This cross-sectional association is also seen during adulthood (Gidlow et al., 2006).

Moreover, there is a life course association between socioeconomic position during childhood and two health outcomes closely related to physical activity during adulthood: obesity (Senese et al., 2009) and cardiovascular diseases (Pollitt et al. 2005). There is also theoretical support from the literature on fundamental movement skills for a life course association between socioeconomic position early in life and physical activity during adulthood (Stodden et al., 2008; Lubans et al., 2010).

Is socioeconomic position during childhood associated with physical activity during adulthood? The first step in examining this association was to review all of the available literature. To this end, we carried out a systematic review (Juneau et al., 2015). We hypothesized that overall, the literature would suggest that socioeconomic position during childhood is associated with physical activity during adulthood. This systematic review answers this thesis' first objective (see section 3): "To determine if the literature supported the hypothesis that there is a life course association between socioeconomic position during childhood and physical activity during adulthood." Authors' contributions are as follows: Carl-Etienne Juneau, Tarik Benmarhnia, Andrée-Anne Poulin, Sylvana Côté, and Louise Potvin contributed to study design, planning, and interpretation of the data. Carl-Etienne Juneau and Tarik Benmarhnia systematically reviewed the literature. Carl-Etienne Juneau, Andrée-Anne Poulin, and Sylvana Côté extracted the data. Carl-Etienne Juneau wrote the manuscript. All authors commented on earlier drafts. This paper is reproduced in full in appendix 1, with permission of Springer. The final version of the original manuscript is presented in the following pages, as required by the University of Montreal's *Faculté des études supérieures et postdoctorales* guidelines.

SOCIOECONOMIC POSITION DURING CHILDHOOD AND PHYSICAL ACTIVITY DURING ADULTHOOD: A SYSTEMATIC REVIEW

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Authors' contributions

CEJ, TB, AAP, SC, and LP contributed to study design, planning, and interpretation of the data. CEJ and TB systematically reviewed the literature. CEJ, AAP, and SC extracted the data. CEJ wrote the manuscript. All authors commented on earlier drafts.

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Conflict of interest

We declare no conflict of interest.

ABSTRACT

Objective: A growing body of evidence links socioeconomic position early in life and physical activity during adulthood. This systematic review aimed to summarize this evidence.

Methods: Medline and EMBASE were searched for studies that assessed socioeconomic position before age 18 years and physical activity at age ≥ 18 years. Studies were rated according to three key methodological quality criteria: (1) Was childhood socioeconomic position assessed prospectively? (2) Was socioeconomic position during adulthood included in the statistical analysis? (3) Was a validated instrument used to measure of physical activity?

Results: Forty-two publications were included. Twenty-six (61.9%) found a significant association between socioeconomic position early in life and physical activity during adulthood. Twenty-one studies met at least two methodological quality criteria. Among those, the proportion was higher: 15/21 (71.4%). Associations were of weak to moderate strength, positive for physical activity during leisure time, and negative for transports and work.

Conclusion: The bulk of the evidence supports the notion that there is a life course association between socioeconomic position early in life and physical activity during

adulthood. Studies using more rigorous methodology supported this conclusion more consistently.

180 words in abstract

KEYWORDS

Public Health, Epidemiology, Physical activity, Longitudinal Studies, Socioeconomic Position, Systematic Review

INTRODUCTION

In 2009, the World Health Organization ranked physical inactivity as the 4th leading risk factor for global mortality. It was estimated that physical inactivity is responsible for 3.2 million deaths each year, or 6% of all deaths (World Health Organization, 2009). Increasing population levels of physical activity thus holds much promise for public health. This task is challenging, as physical activity is a complex behaviour, with many correlates at the individual, environmental, and social levels (Bauman et al. 2012). At the social level, socioeconomic position is a key correlate of physical activity (Trost et al. 2002). Indeed, systematic reviews have found cross-sectional associations between socioeconomic position and physical activity during adolescence (Stalsberg and Pedersen 2010) and during adulthood (Gidlow et al. 2006). That is, low socioeconomic position during adolescence is associated with low levels of physical activity during adolescence (Stalsberg and Pedersen 2010) and low socioeconomic position during adulthood is associated with low levels of physical activity during adulthood (Gidlow et al. 2006).

This raises a question: Is this association is purely cross-sectional, or is there a long-lasting, life course association between socioeconomic position early in life and physical activity during adulthood? This seems plausible, as socioeconomic position early in life has been associated in systematic reviews with three health outcomes during adulthood closely related to physical activity: cardiovascular disease (Pollitt et al. 2005), obesity (Senese et al. 2009), and physical capability levels (Birnie et al. 2011). Moreover, in a systematic review

(Gidlow et al. 2006), physical activity during adulthood was found to be associated with education, an indicator that reflects, at least in part, socioeconomic position during adolescence and early adulthood (Galobardes et al. 2007). We aimed to systematically review and summarize the evidence linking socioeconomic position early in life and physical activity during adulthood. We hypothesized that the bulk of the evidence would support the notion that there is indeed a long-lasting, life course association between socioeconomic position early in life and physical activity during adulthood.

METHODS

Search strategy

Medline (1947-2014 October Week 4) and EMBASE (1974-2014 Week 43) were last searched on October 30, 2014 with no language or date restrictions for studies that assessed socioeconomic position early in life and physical activity during adulthood. Search and screening of title, abstract, and full text for inclusion were carried out by two independent investigators. Discrepancies were solved by mutual agreement. A broad range of keywords related to physical activity, socioeconomic position, and the life course was used (Electronic supplementary material). Reference lists of all included studies were hand searched for additional studies.

Scope of the search and selection criteria

"Early in life" was defined as age lower than 18 years. We chose the term "early in life" to refer to both childhood and adolescence and to avoid any confusion with "childhood socioeconomic position" being interpreted as occurring only during ages 0-12 years (other reviews of childhood socioeconomic position and health outcomes later in life have also included ages 0-17 years; see Pollitt et al. 2005; Senese et al. 2009; Birnie et al. 2011). Adulthood was defined as age ≥ 18 years. Socioeconomic position was defined as a fundamental cause granting access to key resources that can be used to avoid health risks and adopt protective strategies (Link and Phelan 1995). Measures of socioeconomic position included social class, education, income, household amenities, perception of wealth, and area-based measures. Physical activity was defined as bodily movement produced by the contraction of skeletal muscle that increases energy expenditure above the basal level (U.S. Office of the Surgeon General 1996). All types and measures of physical activity were included. Studies were included if: (1) they assessed socioeconomic position at least once for childhood or adolescence (age < 18 years) and (2) they measured physical activity during adulthood (age ≥ 18 years). Studies that used education as the sole measure of socioeconomic position were excluded because a systematic review already reviewed its association with physical activity (Gidlow et al. 2006). Studies that focused on symptomatic population (e.g. cardiovascular patients) were also excluded. All study designs were considered.

Data extraction

Key methodological characteristics and results of each study were recorded in an Excel database. These included: first author, country, date of publication, data source, sample size, age and measures at each point in time across the life course, and magnitude and direction of the associations. Physical activity outcomes were grouped into two categories. The first category was "all types and measures of physical activity." This category included leisure-time physical activity, physical activity at work, physical activity during transports, physical housework, heavy gardening, free-living 24-hour physical activity monitoring by accelerometry, cardiorespiratory fitness tests, musculoskeletal fitness tests, and physical activity diaries. The second category was a subcategory of the first. This category was "leisure-time physical activity only." It included self-reports of physical activity during leisure time, exercise and sports. Studies that had the outcomes "moderate-to-vigorous" or "vigorous" leisure-time physical activity were also included in this category. We chose to consider leisure-time physical activity as a separate outcome because: (1) its scope is easily understood and well-defined, (2) it has a long history of research in public health (Paffenbarger et al. 1978), (3) public health recommendations traditionally have focused on leisure-time physical activity (U.S. Office of the Surgeon General 1996), and (4) it was the most commonly reported outcome. Data extraction was carried out by two investigators. After extraction, discrepancies were solved by mutual agreement.

Data analysis

Our original aim was to carry out a meta-analysis. However, after a preliminary review, we judged that meta-analysis would not be appropriate, because studies were highly heterogeneous (Lau et al. 1998; Egger et al. 2002; Higgins and Green 2011). Important methodological differences were noted among studies. Notably: (1) the age for which childhood socioeconomic position was measured ranged 0-17 years; (2) childhood socioeconomic position was assessed using 12 different indicators; (3) physical activity was measured using 42 different instruments; (4) 16 different statistical techniques were used; (5) 47 different confounding variables were used. Therefore, we choose not to aggregate study results into a single estimate. Instead, we reported proportions of studies that found a significant association. We reported proportions for men and women combined, and stratified by sex. When available, we reported magnitude and direction of significant associations. For direction of associations, in some cases, the outcome was reverse coded (e.g. physical "inactivity"). For example, Regidor et al. (2004) found that low father social class during childhood was significantly associated with more physical inactivity over age 60 years in women. This was considered a positive association nonetheless, as the underlying interpretation is that women whose father had high social class were more active.

Quality assessment

Based on a preliminary review of study methodology, methodological quality assessment focused on three key study characteristics: (1) Was childhood socioeconomic position assessed during childhood in a prospective study design? Assessing childhood socioeconomic position during childhood is likely to provide more valid estimates. Indeed, retrospective recall of social class during childhood is less valid: published estimates of agreement with historical records range from 53.7% (Batty et al. 2005) to 80% (Berney and Blane 1997); (2) Was socioeconomic position during adulthood assessed and included in the multivariate model of physical activity during adulthood, either as an independent, interacting, mediating, or confounding variable? The association of socioeconomic position during adulthood with physical activity during adulthood is well established (Gidlow et a. 2006). Therefore, any association between socioeconomic position early in life and physical activity during adulthood not accounting for socioeconomic position during adulthood may be an artifact of the tracking of socioeconomic position early in life into adulthood (Corcoran 1995). Thus, not including socioeconomic position during adulthood in the model is likely to overestimate the real association between socioeconomic position early in life and physical activity during adulthood. (3) Was physical activity measured using validated methods? In this sample of studies, this included questionnaires with documented validity or reliability, accelerometers (a computerized, portable, objective measure of physical activity), or physical fitness tests (also an objective measure). Studies that referred to any documentation on the reliability or validity of the measurement tool were classified as "yes", regardless of how valid the instrument was. This criterion should therefore not be interpreted as meaning that the instrument used had high validity, although overall, it is likely that studies that used validated methods measured physical activity more accurately than those that did not.

RESULTS

Result of the search

A total of 10,619 papers were found; 653 were retained based on title only. Of those, 135 were retained based on abstract and 48 were retained based on full text. Their reference lists were reviewed and contained two papers which had not already been found (Kimm et al. 2002; Popham and Mitchell 2006). When two papers used data from the same cohort, the older was excluded. Eight studies were thus excluded (Kuh and Cooper, 1992; Yang et al. 1994; Brunner et al. 1999; Lawlor et al. 2004; Lawlor et al. 2005; Wray et al. 2005; Schooling et al. 2008; Walters et al. 2009). This review therefore includes 42 studies. Table 1 presents key characteristics of methodology, a summary of results, and direction of associations. Additional details of methodology and results are show in the Electronic supplementary material.

Measurement of socioeconomic position

All 42 studies assessed socioeconomic position. Eight studies assessed socioeconomic position only once, before age 18 years. The remainder (34 studies) assessed socioeconomic position at least twice: once before age 18 years and once for adulthood. Assessment early in life took place at ages 0 (birth) to 17 years. Eleven different indicators were used: the father's social class, the father's education, the mother's education, the mother's social class, the highest of either parents' social class, the highest of either parents' education, the presence (or absence) of certain household amenities, income, whether the family was perceived as wealthy, family access to a car, neighborhood socio-economic level, and attendance to a fee paying school. Measurement during adulthood took place for ages 18 to 79 years. Fourteen different indicators were used: the subject's own education, social class, employment status, income, area-based measures of socio-economic level, house ownership, car ownership, the household's highest social class, the partner's social class, wealth, job insecurity, skin color, pension arrangements, and perceived family economy.

Measurement of physical activity

All 42 studies measured physical activity; 31 studies had only one outcome for physical activity; 11 had multiple. Physical activity was measured using 42 different instruments. Self-reported leisure-time physical activity (including exercise and sport participation) was the most common outcome (31 studies). Other outcomes included physical activity during transports, physical activity at work, cardiorespiratory fitness, musculoskeletal fitness, walking, cycling, heavy gardening, housework, accelerometry, activity diary, and ad hoc, composite measures based on physical activity in more than one domain of life.

Statistical analysis

Overall, 16 different statistical techniques were used. Logistic regression was the most commonly used technique (it was used in 13 studies). Other techniques included logistic random effects regression, ordinal logistic regression, stratified logistic regression, binomial regression, Poisson regression, multiple regression, generalized estimating equation models, stepwise multiple regression, ANOVA, ANCOVA, t-test, χ^2 test, log multinomial regression, structural equation modeling, and latent class analysis. Likewise, there was much discrepancy in confounding variables. Age and sex were the most common confounders, but overall, 47 different variables were used as confounders.

Association with outcome "all types and measures of physical activity"

A significant association was found between socioeconomic position early in life and at least one measure of physical activity during adulthood in 26 of the 42 studies (61.9%) (Table 2). This was true in 16 of the 31 studies that reported results for men (51.6%), in 13 of the 27 studies that reported results for women (48.2%), and in 5 of the 8 studies that reported results adjusted for sex (62.5%).

Association with outcome "leisure-time physical activity"

A total of 31 studies reported results for leisure-time physical activity as a separate outcome. A significant association was found in 21 of these 31 studies (67.7%) (Table 2). This held true for men in 14 out of 25 studies (56%), for women in 12 out of 22 studies (54.6%), and for sex-adjusted analyses in 1 out of 4 studies (25%).

Magnitude and direction of associations

Most associations were weak to moderate. The strongest association reported was OR (95% CI) = 2.45 (1.25 - 4.80) (Aarnio et al. 2002). The weakest significant association was OR (95% CI) = 0.94 (0.90 - 0.99) (Hillsdon et al. 2008). Magnitude of associations should be interpreted with caution as methodology varied widely across studies (differences in measurement, statistical technique, and confounders may explain differences in magnitudes of associations). Direction of associations by sex are shown in Table 3 for outcomes reported in at least two studies (for clarity, outcomes reported in only one study and studies that used an ad hoc, composite measure based on physical activity in more than one domain were excluded from Table 3, as these cannot be readily compared). For leisure-time physical activity, for men, 13/25 studies (52%) found a positive association (i.e. high socioeconomic position early in life, high physical activity during adulthood), 11/25 studies (44%) found no association, and 1/25 study (4%) found a negative association. For women, 11/22 studies (50%) found a positive association, 10/22 studies (45.5%) found no association, and 1/22 study (4.5%) found a negative association. In sex-adjusted analyses, 1/4 study (25%) found a positive association and 3/4 studies (75%) found no association. Other outcomes were less studied. Only four studies measured cardiorespiratory fitness (Barnekow-Bergkvist et al. 1998; Poulton et al. 2002; Cleland et al. 2009; Svedenkrans et al. 2013). Poulton et al. (2002) and Cleland et al. (2009) adjusted for sex and found a positive association. Svedenkrans et al. (2013) studied men only. They found a positive association as well. Barnekow-Bergkvist et al. (1998) stratified results by sex and found no association. Therefore, overall, a positive association was found for cardiorespiratory fitness in 3/4 studies (75%), whereas no association was found in 1/4 study (25%). Only three studies reported results for physical activity at work as a separate outcome (Silverwood et al. 2012; Mann et al. 2013; Juneau et al. 2014). All three were carried out in recent years in the UK. Of those, one study found no association and two studies found a negative association. The same three studies also reported results for physical activity during transports as a separate outcome. Similarly, one study found no association and two studies found a negative association (although for women only in Juneau et al. 2014; no association was found for men in that study).

Methodological quality assessment

Of the 42 studies, 23 (54.8%) measured childhood socioeconomic position during childhood in a prospective study design. Nineteen (45.2%) included socioeconomic position during adulthood in their statistical analysis. Twenty-one (50%) measured physical activity using validated methods. Overall, five studies (11.9%) met all three quality criteria; 16 studies (38.1%) met two; 15 studies (35.7%) met one; six studies (14.3%) met zero (Table 1).

Evidence from studies using more rigorous methodology

Overall, 21 studies met at least two of the three methodological quality criteria. This was considered a subset of studies using more rigorous methodology. In this subset, 15 studies (71.4%) reported a significant association between socioeconomic position early in life and the outcome "all types and measures of physical activity" during adulthood. This was true for men in 12/16 studies (75%), for women in 6/14 studies (42.9%), and for sex-adjusted analyses in 3/5 studies (60%). For the outcome "leisure-time physical activity only," a significant association was found in 12/15 studies (80%). This was true for men in 10/12 studies (83.3%), for women in 6/12 studies (50%), and for sex-adjusted analyses in 0/2 studies (0%).

DISCUSSION

This systematic review aimed to summarize the evidence linking socioeconomic position early in life and physical activity during adulthood. We hypothesized that the bulk of the evidence would support the notion that there is indeed a long-lasting, life course association between socioeconomic position early in life and physical activity during adulthood. Overall, the results of this systematic review provided support for our hypothesis.

Using a broad set of keywords, we found 10,619 published studies. We retained studies of all designs that assessed socioeconomic position at least once early in life (age < 18 years) and that measured physical activity during adulthood (age ≥ 18 years). A total of 42 studies were retained. Socioeconomic position before age 18 years and physical activity during adulthood were associated in 26 of the 42 studies (61.9%). This proportion increased to 21/31 (67.7%) when we focused on leisure-time physical activity only as the outcome. This proportion further increased in studies that met at least two of our three methodological quality criteria (prospective measurement of childhood socioeconomic position, statistical inclusion of socioeconomic position during adulthood, and use of a validated instrument to measure physical activity). In this subset of studies using more rigorous methodology, a significant association between socioeconomic position early in life and physical activity during adulthood was found in 15/21 studies (71.4%) for all types and measures of physical activity and in 12/15 studies (80%) for leisure-time physical activity only as the outcome. Associations were in the expected direction for leisure-time physical activity (i.e. high socioeconomic position early in life, high leisure-time physical activity during adulthood). Only one study found a negative association between these two variables (Barnekow-Bergkvist et al. 1998). Other outcomes were less studied. The evidence pointed to a positive association for cardiorespiratory fitness (3/4 studies) and to a negative association for physical activity during transports (2/3 studies) and at work (2/3 studies). Overall, these results suggest that: (1) there is indeed a long-lasting, life course association between socioeconomic position early in life and physical activity during adulthood; (2) studies using more rigorous methodology supported this conclusion more consistently; (3) associations for leisure-time physical activity were found more consistently than for physical activity in other domains of life; (4) direction of associations appeared to be positive for leisure-time physical activity and cardiorespiratory fitness and negative for physical activity during transports and at work.

Our results are in line with those of other systematic reviews that found associations between socioeconomic position early in life and health outcomes during adulthood (Senese et al. 2009; Pollitt et al. 2005; Birnie et al. 2011). Senese et al. (2009) systematically reviewed the literature on socioeconomic position during childhood and obesity during adulthood. They reported that 70% of studies of females found decreasing obesity during adulthood with increasing socioeconomic position during childhood (this association was found for males in only 27% of studies, however). Similarly, in their systematic review for cardiovascular diseases, Pollitt et al. (2005) found that "studies reviewed provided moderate support for the role of low early-life socioeconomic status and elevated levels of cardiovascular disease risk factors and cardiovascular disease morbidity and mortality." Lastly, in a meta-analysis, Birnie et al. (2011) found evidence that lower childhood socioeconomic position was associated with modest reductions in physical capability levels in adulthood. Taken as a whole, this body of literature seems to suggest that socioeconomic position early in life is consistently associated with health outcomes during adulthood.

We were hesitant to report the strength of the associations in the studies we systematically reviewed, for a number of reasons related to methodology. Methodology varied widely across studies: (1) most studies stratified results by sex, but some adjusted for sex, and one reported both stratified and adjusted results; (2) most studies assessed socioeconomic position twice, but some assessed it just once (early in life), and a few assessed it three times or more across the life course; (3) socioeconomic position before age 18 years was assessed using 11 different indicators; (4) there was no consistent age for assessment of socioeconomic position before age 18 years (assessment took place for ages 0 to 17 years) or during adulthood (assessment took place for ages 18 to 79 years); (5) socioeconomic position during adulthood was assessed using 14 different indicators; (6) physical activity was measured using 42 different instruments; (7) 16 different statistical techniques were used; (8) 47 different confounding variables were used. No two studies used the same design: even in studies that used the same statistical technique, confounders, measurement of socioeconomic position, or measurement of physical activity were different. As strength of association is dependent on measurement and handling of data, study results should be compared with caution. For example, the strongest association reported was OR (95% CI) =

2.45 (1.25 - 4.80) (Aarnio et al. 2002). In this study, there was thus an increased risk of "persistently inactive" status (a dichotomous variable defined as exercise 1-2 times a month or less for three years consecutively, at ages 16, 17, and 18 years). It was found in young men whose father was self-employed vs. upper level employee (reference category). Logistic regression was used, and the model was adjusted for smoking, alcohol use, breakfast eating, school type, school grade, and own perception of current health. Compare this with the weakest significant association reported: OR (95% CI) = 0.94 (0.90 - 0.99) (Hillsdon et al. 2008). In that study, there was thus a lower risk of being more physically active (defined as an ordinal variable with four categories of increasing weekly hours spent in the following activities: brisk walking, cycling, heavy gardening, and leisure-time physical exercise such as tennis). It was found in women aged 60-79 years. Risk of being more physically active decreased as values on a composite indicator of childhood socioeconomic position increased (this indicator comprised, for childhood: father manual social class, no bathroom at home, no hot water at home, no car access, and shared bedroom). Ordinal logistic regression was used, and the model was adjusted for age, smoking, BMI, cardiovascular disease, respiratory disease, and adult socioeconomic position (including adult social class, housing tenure, car ownership, pension arrangements, and area-level deprivation). How can we explain the differences in results between these two studies? It could be the sample (young men vs. older women) or the country (Finland vs. UK), but it could also be the measure of socioeconomic position (self-employed father vs. composite indicator), the measure of physical activity (persistently inactive vs. a combination of walking, cycling, gardening, and leisure-time exercise), or the choice of confounders. Until there is more standardization in life course studies of socioeconomic position and physical activity, we believe that only a general, cautious interpretation of this body of literature is in order. We further believe that strengths of associations should not be compared directly and that meta-analysis would not be appropriate.

To improve standardization in future research, we suggest a number of guidelines. Future research should measure physical activity using validated methods. Of the 42 studies we included in this systematic review, only 21 (50%) did so. Validated questionnaires were often used. These are a step in the right direction, but validated questionnaires are still prone to significant measurement error. Indeed, systematic reviews have concluded that self-reports of physical activity are inaccurate (Prince et al. 2008), even when validated questionnaires are used (Lee et al. 2011). Therefore, the results obtained in the 21 studies included in this systematic review (50% of our sample) that did not use validated methods to measure physical activity should be interpreted with caution. In addition, even when validated questionnaires were used, internal validity could have been improved by using objectives measures such as accelerometers. Accelerometers can be used in subsamples when budgets are limited. They are generally regarded as providing more valid estimates than questionnaires (Prince et al. 2008). However, they do readily not distinguish between domains of physical activity. Therefore, depending on the study objective, questionnaires may still be useful to assess separately physical activity during leisure-time, during transports, at work, and at home. Whenever possible, we recommend a combination of methods to measure physical activity in future research: objectives measures to obtain more valid estimates and questionnaires to assess physical activity in each domain of life separately. Some authors have done this (Silverwood et al. 2012; Mann et al. 2013; Juneau et al. 2014), but other have collapsed multiple domains of physical activity into one single composite measure (Bell and Lee, 2006; Bowen 2010; Hart et al. 2008; Heraclides et al. 2008; Hillsdon et al. 2008; Kamphuis et a. 2013; Osler et al. 2007; Osler et al. 2008). For example, Hart et al. (2008) combined data on "usual daily activity" (i.e. work) and "physical activity during non-working time" (i.e. leisure time) into a single measure. These outcomes are generally associated with socioeconomic position in different directions (i.e. higher socioeconomic position, more physical activity during leisure time and less physical activity at work). Thus, perhaps not surprisingly, Hart et al. (2008) found no association between their composite measure of physical activity and socioeconomic position during childhood. A final reason to use validated questionnaires or accelerometers is to enable comparisons between studies. In our sample, studies that did not use validated questionnaires used their own ad hoc measure of physical activity. This made comparisons across studies difficult.

In addition, future research on life course socioeconomic position should assess childhood socioeconomic position during childhood in a prospective study design. While commonly done in life course research, assessing childhood socioeconomic position retrospectively during adulthood may involves substantial measurement error and recall bias. Indeed, published estimates of agreement between retrospective recall and historical records range from 53.7% (Batty et al. 2005) to 80% (Berney and Blane 1997). Berney and Blane (1997) collected information from 57 UK subjects aged 64 to 83 years and compared it with archive material of the same subjects' social circumstances recorded 50 years previously. Their sample comprised subjects from two historical cohorts. In the first cohort, 80% of subjects recalled their father's occupation correctly. In the second cohort, 66% of subjects did so. Batty et al. (2005) analyzed data from a cohort of 12,150 children who took part in a school based survey in 1962. In this survey, information was collected about the father's occupation at birth (reported by the mother at birth) and the father's occupation during childhood (reported in 1962 at age 6-12 years by children). Between 2000 and 2003, a questionnaire was mailed to traced cohort members. A total of 7,183 (63.7%) persons responded to the mid-life questionnaire. Subjects recalled their father's occupation at birth correctly in 53.7% of cases, and that of their father during their childhood (at age 6-12 years) in 61.4% of cases. Of the 42 studies included in our systematic review, only 23 (54.8%) assessed childhood socioeconomic position prospectively during childhood. The remainder measured it during adulthood using retrospective recall. The evidence we have briefly reviewed here suggests that these studies' results should be interpreted with caution.

Moreover, in future research, we recommend that investigators include socioeconomic position during adulthood in their statistical analysis. This variable should be included as an independent, interacting, mediating, or confounding variable, based on the conceptual model that guides the study, as the association of socioeconomic position during adulthood with physical activity during adulthood is well established (Gidlow et al. 2006). As socioeconomic position tracks across the life course (Corcoran 1995), any association between socioeconomic position early in life and physical activity during adulthood unadjusted for socioeconomic position during adulthood is likely to be overestimated. In addition, whenever possible, socioeconomic position and physical activity should be assessed at multiple points in time across the life course, as both may fluctuate. Finally, future research, if possible, should try to determine whether the association between socioeconomic position early in life and physical activity during adulthood is graded, to strengthen causal inference.

How can we explain the association between socioeconomic position early in life and physical activity, especially leisure-time physical activity, during adulthood? While a comprehensive answer is beyond the scope of this review, the literature on fundamental movement skills may shed some light on this question. Fundamental movement skills are basic motor skills. They include skills like running and hopping (locomotor skills), catching and throwing (object control), and balancing and twisting (stability) (Lubans et al. 2010). They are "considered to be the building blocks that lead to specialized movement sequences required for adequate participation in many organized and non-organized physical activities for children, adolescents and adults" (Stodden et al. 2008). Stodden et al. (2008) proposed that "fundamental movement skills competency interacts with perceptions of motor competence and health-related fitness to predict physical activity and subsequent obesity from childhood to adulthood." Thus, according to this literature, early childhood and adolescence may both be sensitive periods for physical activity later in life (because fundamental movement skills are learned during early childhood and because they are refined into specialized movement sequences during adolescence). Systematic review evidence that low socioeconomic position during adolescence is associated with low physical activity during adolescence (Stalsberg and Pedersen 2010) supports this hypothesis. Systematic review evidence that school-based interventions focusing on physical activity, fitness, or fundamental movement skills increase physical activity later in life further support this hypothesis (Lai et al. 2014). More research is needed to test this hypothesis, and the potential role of fundamental movement skills as a mediator between low socioeconomic position early in life and low physical activity during adulthood.

A limitation of this systematic review is that nearly all studies were carried out in high-income countries (including 17 in Scandinavian countries and 10 in the UK). Therefore, their conclusions should not be overly generalized to others settings, especially to lower income countries.

In conclusion, the bulk of the evidence we have reviewed in this systematic review supported the hypothesis that there is a long-lasting, life course association between socioeconomic position early in life and physical activity during adulthood. This hypothesis was supported more consistently for leisure-time physical activity and in studies using more rigorous methodology. To strengthen methodology in future research, we recommend that researchers (1) measure physical activity using accelerometers in subsamples, (2) report results for each domain of physical activity separately, (3) assess childhood socioeconomic position prospectively during childhood, and (4) include socioeconomic position during adulthood in their statistical analysis.

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Table 1 Key characteristics of methodology, summary of results, and direction of associations in the 42 studies included in this systematic review of socioeconomic position before age 18 years and physical activity at age ≥ 18 years (the literature search was done without country or year restriction; SEP: socioeconomic position, PA: physical activity, LTPA: leisure-time physical activity, OR: odds ratio, RR: relative risk; CRF: Cardiorespiratory fitness, MSF: Musculoskeletal fitness)

First authors (year of publication) country	Measurement SEP early in life	Adulthood SEP included analysis?	Validated measure of PA?	Quality score	Result summary	Direction of association
Mann (2013) UK	Prospective	Yes	Yes	3	No associations between the father's social class at birth and sport, occupational, commuting, and household physical activity	Men and women combined LTPA: no association Transport: no association Work: no association Household: no association
Osler (2001) Denmark	Prospective	Yes	Yes	3	No associations between the father's education at age 3-17 years and leisure-time physical activity age 19-31 years	Men LTPA: no association Women LTPA: no association
Poulton (2002) New Zealand	Prospective	Yes	Yes	3	Low parental social class from birth to age 15 years significantly associated with lower cardiorespiratory fitness at age 26 years for men and women. Downward social mobility between 0-15 years and 26 years significantly associated with lower cardiorespiratory fitness at age 26 years for men and women.	Men and women combined CRP: positive association
Barnekow-Bergkvist (1998) Sweden	Prospective	Yes	Fitness: yes Transport: no LTPA: no	2 or 3	Father in manual work significantly associated with stronger two-hand lift and weaker standing balance at age 33 years for men only. Working mother (for men) and father in manual work (for women) significantly associated with more sport activities at age 33-36 years	Men LTPA: negative association CRF: no association MSF: positive association Women LTPA: negative association CRF: no association MSF: no association

Silverwood (2012) UK	Prospective	Yes	Cycling: no LTPA: yes	2 or 3	Upward social mobility significantly associated with more sedentary behavior during the working day and less walking for men only. Upward social mobility significantly associated with more leisure-time physical activity for men and women. Downward social mobility significantly associated with less sedentary behavior, more walking, and less leisure-time physical activity for men and women. Upward educational mobility significantly associated with more sedentary behavior during the working day, less walking, and more leisure-time physical activity for men and women Downward educational mobility less sedentary behavior during the working day (for men and women), more walking (for men only), but less leisure-time physical activity (for women only) Low father education at age 6 years significantly associated with less sedentary behavior during the working day, more walking, less leisure-time physical activity (for men and women) and more cycling (women only). Low father's social class at age 4 years significantly associated with less sedentary behavior during the working the day for men only, more walking, and less leisure-time physical activity at age 36 years for men and women	Men LTPA: positive association Transport: negative association Work: negative association Women LTPA: positive association Transport: negative association Work: negative association
Aarnio (2002) Finland	Prospective	No	Yes	2	Self-employed father at age 16 years significantly associated with higher odds of persistently inactive status from ages 16 to 18 years for men only. Self-employed mother at age 16 years significantly associated with lower odds of persistent exerciser status from ages 16 to 18 years for men only	Men LTPA: positive association Women LTPA: no association
Beunen (2004) Belgium	Prospective	No	Yes	2	Higher father education at age 18 years significantly associated with higher sport and leisure-time indexes at age 40 years. Higher father's social class at age 18 years significantly associated with higher leisure-time index at age 40 years	Men only LTPA: positive association
Bratteby (2005) Sweden	Prospective	No	Yes	2	High mother education at age 21 years significantly associated with lower total energy expenditure, activity energy expenditure, and physical activity level at age 21 years	Men and women combined Whole-day: negative association
Cleland (2009) Australia	Retrospective	Yes	Yes	2	Highest parent's education at ages 0-12 years significantly associated with decreasing fitness and persistently unfit status from ages 9-15 to 26-36 years. High mother education and medium father education at ages 0-12 years significantly associated with persistently fit status from ages 9-15 years to 26-36 years. Persistently high socioeconomic position and upward social mobility from ages 0-12 to 26-36 years significantly associated with less decreasing and more increasing activity and fitness at age 26-36 years	Men LTPA: positive association Women LTPA: no association Men and women combined CRF: positive association
Hart (2008) UK	Prospective	Yes	No	2	No associations between the father's social class at age 10-39 years and usual daily activities at age 30-59 years for men and women.	Men Whole-day: no association Women Whole-day: no association

Huurre (2003) Finland	Prospective	Yes	No	2	Manual father social class at age 16 years significantly associated with less leisure-time physical activity at age 22 years for men only	Men LTPA: positive association Women LTPA: no association
Juneau (2014) UK	Prospective	Yes	No	2	Social class at ages 0, 5, 10, 30, and 34 years were associated with physical activity at age 34 years, although the magnitude and the direction of the associations for social class at each age varied by physical activity outcome and by sex	Men LTPA: positive association Transport: no association Work: negative association Women LTPA: positive association Transport: negative association Work: negative association
Kimm (2002) USA	Prospective	No	Yes	2	Black skin color at age 8-9 years associated with a 100% decline in leisure-time physical activity levels by age 16-17 years (remaining so at 18-19 years). Low parental education at age 8-9 years significantly associated with low leisure-time physical activity at age 18-19 years in white and black girls	Women only LTPA: positive association
Kvaavik (2012)Norway	Prospective	Yes	No	2	No associations between the father's education or the mother's education at age 11-15 years and leisure-time physical activity at ages 13-17 years, 23-27 years, 31-35 years, and 38-42 years	Men and women combinedLTPA: no association
Osler (2007) Denmark	Retrospective	Yes	Yes	2	No association between social class during childhood and walking, running and biking at age 46-69 years	Men Composite: no association Women Composite: no association
Osler (2008) Denmark	Prospective	Yes	No	2	No associations between the father's social class at birth and walking, running and biking at age 51 years for men	Men only Composite: no associations
Sagatun (2008) Norway	Prospective	No	Yes	2	High father income at age 17-18 years significantly associated with more leisure-time physical activity at age 18-19 years in ethnic Norwegian and ethnic minority women. Low mother education at age 17-18 years significantly associated with less leisure-time physical activity at age 18-19 years in ethnic Norwegian women only.	Men LTPA: no association Women LTPA: positive association
Salonen (2011) Finland	Prospective	No	Yes	2	High father social class at birth significantly associated with higher frequency of leisure-time physical activity at age 57-70 for men only.	Men LTPA: positive association Women LTPA: no association
Svedenkrans (2013) Sweden	Prospective	No	Yes	2	Highest parent's education, social class, and income at age 7-17 years significantly associated with higher cardiorespiratory fitness at age 18-26 years	Men only CRF: positive association

Taverno Ross (2014) USA	Prospective	No	Yes	2	Foreign-born at age 14.9 ± 1.6 years significantly associated with less moderate-to-vigorous leisure-time physical activity at age 25.3 ± 1.6 years for men only	Men LTPA: positive association Women LTPA: no association
Telama (2009) Finland	Prospective	No	Yes	2	Low father education at age 12-18 years significantly associated with less leisure-time physical activity across the life course up to age 40-46 years for men and women	Men LTPA: positive association Women LTPA: positive association
Azevedo (2008) Brazil	Prospective	Not specified (unclear, classified as no)	Yes	1	Family income at birth, persistently low income, and downward income mobility from birth to age 22-23 years significantly associated with leisure-time sedentary lifestyle at age 22-23 years for men and women.	Men LTPA: positive association Women LTPA: positive association
Bell (2006) Australia	Retrospective	No	Yes	1	No significant associations between the highest parent's social class during childhood and physical activity at age 22-27 years. Women only	Women only Composite: no association
Blane (1996) UK	Retrospective	Yes	No	1	No significant associations between the father's social class during childhood and recreational exercise at age 35-64 years	Men only LTPA: no association
Elwell-Sutton (2011) China	Retrospective	No	Yes	1	No significant associations between parental possessions during childhood and leisure-time physical activity over age 50 years	Men and women combined LTPA: no association
Heraclides (2008) UK	Retrospective	No	Yes	1	No associations between the father's social class during childhood and walking, cycling, sports, gardening activities, housework, and house maintenance physical activity at age 45-68 years for men and women	Men Composite: no association Women Composite: no association
Hillsdon (2008) UK	Retrospective	Yes	No	1	Low childhood socioeconomic position significantly associated with lower walking, cycling, heavy gardening, and physical exercise at age 60-79 years for women	Women only Composite: positive association
Leino (1999) Finland	Retrospective	Yes	No	1	No associations between the highest parent's education during childhood and exercise at age 21-30 years	Men LTPA: no association Women LTPA: no association
Lynch (1997) Finland	Retrospective	No	Yes	1	Poor or middle score on index of socioeconomic conditions at age 10 years signficantly associated with less leisure-time physical activity at age 42-60 years (men only)	Men only LTPA: positive association

Øygard (1998) Norway	Prospective	No	No	1	No associations between the father's education at age 11-14 years and leisure-time physical activity at age 23-26 years for men and women	Men LTPA: no association Women LTPA: no association
Popham (2006) UK	Retrospective	Yes	No	1	Having attended a fee paying school during childhood significantly associated with more leisure-time physical activity at age 18-64 years for women only	Men LTPA: no association Women LTPA: positive association
Pudrovska (2012) USA	Retrospective	Yes	No	1	High family socioeconomic status at age 17-18 years significantly associated with more leisure-time physical activity at age 64-65 years for men and women.	Men LTPA: positive association Women LTPA: positive association
Regidor (2004) Spain	Retrospective	Yes	No	1	Low father social class during childhood significantly associated with more physical inactivity over age 60 years for women only	Men LTPA: no association Women LTPA: positive association
Salonna (2008)Slovakia	Prospective	No	No	1	Low highest parent's education and low highest parent's social class at age 14-15 years significantly associated with less sport at age 18-19 years for women only.	MenLTPA: no associationWomenLTPA: positive association
Tammelin (2003) Finland	Prospective	No	No	1	No associations between for father social class at age 14 years and leisure-time physical activity at age 31 years for men and women	Men LTPA: no association Women LTPA: no association
Van de Mheen (1998) Netherlands	Retrospective	Yes	No	1	Low father social class at age 12 years significantly associated with lower odds of frequent physical activity at age 25-74 years for women only No associations for "no physical activity" for men and women	Men LTPA: no association Women LTPA: positive association
Bowen (2010) USA	Retrospective	No	No	0	Low mother education, low father education, and manual father social class during childhood significantly associated with less physical activity over age 50 years	Men and women combined Composite: positive association
Heslop (2001) UK	Retrospective	No	No	0	No associations between the father's social class during childhood and recreational exercise at age 35-64 years	Women only LTPA: no association

Suppli (2013) Denmark	Retrospective	No	No	0	Low vigorous physical activity at age 15 years significantly associated with low vigorous physical activity at age 27 years only in participants with low socioeconomic position during childhood.	Men and women combined LTPA: positive association
Kamphuis (2013) Netherlands	Retrospective	No	No	0	No associations between the father's social class at age 12 years and leisure-time physical activity, sports, and transport-related physical activity at age 40-75 years for men	Men only Composite: no association
Kittleson (2006) USA	Retrospective	No	No	0	No associations between the father's social class during childhood and physical training at age 26 years	Men only LTPA: no association
Ramsay (2007) UK	Retrospective	No	No	0	Low father social class during childhood significantly associated with inactive lifestyle at age 52-73 years	Men only LTPA: positive association

Studies are ordered by quality score.

Table 2 Summary of associations between socioeconomic position before age 18 years and physical activity during adulthood in the 42 studies included in this systematic review (no country or date restriction)

		Significant association	No association	Total	% significant
All studies	*All types and measures of physical activity*	26	16	42	61.9%
	Leisure-time physical activity only	21	10	31	67.7%
More rigorous methodology	*All types and measures of physical activity*	15	6	21	71.4%
	Leisure-time physical activity only	12	3	15	80.0%

Table 3 Direction of associations between socioeconomic position before age 18 years and physical activity during adulthood for outcomes reported in at least two studies, by sex (no country or date restriction)

		Positive association	No association	Negative association	Total	% positive
Men	*Cardiorespiratory fitness**	3	1		4	75.0%
	Leisure-time physical activity	13	11	1	25	52.0%
	Physical activity at work		1	2	3	0%
	Physical activity during transports		2	1	3	0%
		Positive association	**No association**	**Negative association**	**Total**	**% positive**
Women	*Cardiorespiratory fitness**	2	1		3	66.7%
	Leisure-time physical activity	11	10	1	22	50.0%
	Physical activity at work		1	2	3	0%
	Physical activity during transports		1	2	3	0%

*Results for cardiorespiratory fitness were pooled for men and women in 3 of the 4 studies.

Electronic supplementary material

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Socioeconomic position early in life and physical activity during adulthood: a systematic review

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Search strategy

Electronic search

Medline and EMBASE were searched with no language or date restrictions for studies that focused on the association between socioeconomic position during childhood or adolescence and physical activity during adulthood.

Timeframe of search

Medline (1947-2014 October Week 4) and EMBASE (1974-2014 Week 43) were last searched on October 30, 2014.

Keywords

First, we drafted a comprehensive keyword list. To this end, we (1) wrote down every keyword we could think of, (2) reviewed the keyword list of 14 studies identified in a preliminary search, and (3) added all keywords two studies were indexed for in Medline and EMBASE (Hillsdon et al. 2008; Cleland et al. 2009). This yielded a broad keyword list. When entered in Medline and EMBASE, this list generated over 100,000 search results. Reviewing that many results was judged unrealistic and wasteful. Therefore, an iterative process began in which the less relevant keywords were removed one by one until the remainder generated a reasonable number of results. This shorter list was then entered in Medline and EMBASE in Ovid under the “Advanced Search” tab. The keywords in this shorter list are shown in the Table (* denotes a wildcard).

Selection criteria

Studies were included if: (1) they assessed socioeconomic position at least once during childhood or adolescence (age < 18 years) and (2) they measured physical activity at least once during adulthood (age ≥ 18 years). Studies that used education as the sole measure of socioeconomic position were excluded because a systematic review already reviewed its association with physical activity (Gidlow et al. 2006). Studies that focused on symptomatic population (e.g. cardiovascular patients) were also excluded. All study designs were considered.

Table 1 Medline (1947-2014 October Week 4) and EMBASE (1974-2014 Week 43) search in Ovid (the search was done without country or year restriction)

Line number	Query	Return
#1	Physical activity or Exercise or Sport or Motor activity or Leisure-time physical activity or Fitness or VO2max or LTPA	920,119
#2	Inequalities or Inequities or Disparities or Social inequalities or Social circumstances or Social conditions or Social class or Social status or Social mobility or Poverty or Education or Socioeconom* or Socio-econom*	1,859,650
#3	Life course or Lifecourse or Life-course or Life cycle or Longitudinal or Cohort or Follow-up stud*	1,657,637
#4	1 and 2 and 3	10,619

Table 2 Additional methodological and results details for the 42 studies included in this systematic review of socioeconomic position before age 18 years and physical activity at age ≥ 18 years (the literature search was done without country or year restriction; SEP: socioeconomic position, LTPA: leisure-time physical activity, IPAQ: International Physical Activity Questionnaire, BMI: Body mass index, SE: Standard error, SD: Standard deviation)

First authors (year of publication) country	Sample size (analytical n when available)	Age baseline (years)	Age last follow-up (years)*	Age and measures at time point 1	Age and measures at time point 2	Age and measures at time point 3	Statistical technique	Confounders	Key result
Mann (2013) UK	216 men 261 women	0	49-51	0 years Father's social class	49-51 years Own social class Own education Sport, occupational, commuting, and household physical activity (questionnaire based on Kuh and Cooper 1992)		Logistic regression	Sex, BMI, smoking status, long-term illness	Not significant
Osler (2001) Denmark	162 men 155 women	6-18	19-31	6-18 years Father's education (measured when participants were aged 3-17 years)	19-31 years Own education Leisure-time physical activity (questionnaire based on Haglund 1984) Sports participation (questionnaire) Physical activity at work (questionnaire)		Logistic regression	Age, sex, work activity, smoking status	Not significant
Poulton (2002) New Zealand	931 adults	0	26	0-15 years Highest parent's social class	26 years Own social class Cardiorespiratory fitness (cycle ergometer test)		Multiple regression t-test	Sex, infant health	Men and women combined Low vs high parental socioeconomic status beta (SE) = -2.54 (1.14), p = 0.03 Downward mobility T = 2.02, p = 0.04

Barnekow-Bergkvist (1998) Sweden	157 men 121 women	15-18	33-36	15-18 years Cardiorespiratory fitness (9-min walk-run distance test) Muscular endurance and strength (bench press, sit-ups, two-hand lift, hand grip, Sargent jump, hanging and lying leg-lift) Standing balance Participation in leisure-time sports activity, number of sports activities, and membership of sports clubs (questionnaire)	33-36 years Own education Own social class (timeframe of measurement not specified) Father's social class (timeframe of measurement not specified) Mother's social class Cardiorespiratory fitness (cycle ergometer test) Muscular endurance and strength (bench press, sit-ups, two-hand lift, hand grip, Sargent jump, back extension, and curl-ups) Walking/cycling to work, summer/winter sport activities (questionnaire)		Multiple regression	Sex, anthropometric measures, attitudes to physical activity, marks in physical education	Men Father manual worker beta two-hand lift = 0.17 Father manual worker beta standing balance = -0.27 Working mother beta sport activities beta = 0.19 Women Father manual worker beta sport activities = 0.18

Silverwood (2012)UK	1,940 men1,907 women	0	53	4 yearsFather's social class6 yearsFather's education	26 yearsOwn education	31 years: Cycling (questionnaire)36 years: Own or household's highest social class; Sedentary behavior; Walking; Cycling; Leisure-time physical activity (questionnaire)43 years: Walking; Cycling; Leisure-time physical activity (questionnaire)53 years: Leisure-time physical activity (questionnaire based on the Minnesota leisure-time activity questionnaire)	Latent class analysisLogistic regression	Sex	MenLow LTPA by father social class: IV and V (51.9%), III manual (45.1%), III non-manual (37.7%), I and II (39.9%), p for trend < 0.001WomenLow LTPA by father social class: IV and V (55.8%), III manual (50.7%), III non-manual (36.7%), I and II (33.8%), p for trend < 0.001
Aarnio (2002) Finland	2,254 men 2,652 women	16	18	16 years Frequency of leisure time physical activity outside school, subjects' own perception of their physical fitness, intensity of physical activity (validated questionnaire) Father's social class Mother's social class	17 years Own education Frequency of leisure time physical activity outside school, subjects' own perception of their physical fitness, intensity of physical activity (validated questionnaire)	18 years Frequency of leisure time physical activity outside school, subjects' own perception of their physical fitness, intensity of physical activity (validated questionnaire)	Logistic regression	Sex, smoking, alcohol, breakfast eating, school type, school grade, own perception of current health, BMI	Men Self-employed father OR inactive (95% CI) = 2.45 (1.25 - 4.80) Self-employed mother OR exerciser (95% CI) = 0.25 (0.08 - .077) Women Not significant

Beunen (2004) Belgium	166 men	13-18	40	13-18 years Performance and health-related fitness (various physical tests) Cardiorespiratory fitness (step test) The father's and mother's social class (at age 18 years) The father's and mother's education (at age 18 years)	40 years Own social class Work index, sport index, and leisure-time physical activity index (Baecke questionnaire) Activity counts (triaxial accelerometry)		Stepwise multiple regression	None	Men only Father education beta sport index = 0.19 Father education beta leisure-time index = 0.14 Father social class beta leisure-time index = 0.16
Bratteby (2005)Sweden	71 men89 women	15	21	15 yearsTotal energy expenditure, activity energy expenditure, and physical activity level (activity diary based on Bouchard et al. 1983)Type and duration of transport to school or work, duration of daily sitting, participation in physical education, membership of a sports club, physical training in leisure time, and competitive sports (questionnaire based on Bratteby et al., 1998)Father's and mother's educationFamily housing conditions	21 yearsTotal energy expenditure, activity energy expenditure, and physical activity level (activity diary based on Bonchard et al. 1983)Type and duration of transport to school or work, duration of daily sitting, participation in physical education, membership of a sports club, physical training in leisure time, and competitive sports (questionnaire based on Bratteby et al., 1998)Father's and mother's educationFamily housing conditionsOwn employement		Stepwise multiple linear regression	Weight, height, sitting time per day, mother's education, region of domicile, sex, regular training, competitive activity, and employement	Men and women combinedMother education beta total energy expenditure = -0.09, p = 0.0155

Cleland (2009) Australia	2,905 adults	7-15	26-36	7-15 years Active commuting to and from school and school physical education, school sport, and nonorganized physical activity outside of school hours (questionnaire) (subjects aged 9-15 years only) Cardiorespiratory fitness (bicycle ergometer test, 2595 subjects aged 9, 12, and 15 years only)	26-36 years Father's and mother's education (measured retrospectively for ages 0-12 years) Own education Leisure-time physical activity (IPAQ, 2679 subjects only) Cardiorespiratory fitness (cycle ergometer test, 2032 subjects only)	Log multinomial regression	Age, sex	Men LTPA Upward social mobility RR decreasingly active/fit (95% CI) = 0.57 (0.39-0.82) Upward social mobility RR increasingly active/fit (95% CI) = 1.49 (1.06-2.09) Women LTPA Not significant Men and women combined CRP Fitness Highest parent's education RR decreasingly fit (95% CI) = 1.36 (1.04-1.79) Highest parent's education RR persistently fit (95% CI) = 0.67 (0.46-0.97) High mother education (vs low) RR persistently fit (95% CI) = 1.59 (1.17-2.16) Medium father education (vs low) RR persistently fit (95% CI) = 0.64 (0.44-0.94)
Hart (2008)UK	1,040 men1,298 women	10-39	30-59	10-39 yearsFather's and mother's social class	30-59 yearsOwn social classOwn educationHouse ownershipCar ownershipUsual daily activity and physical activity during non-working time (questionnaire)	Logistic regression	Age, sex	Not significant

Huurre (2003) Finland	763 men 886 women	16	22	16 years Father's social class Leisure-time physical activity (questionnaire)	22 years Own education Leisure-time physical activity (questionnaire)		Logistic regression	Sex	Men Father social class manual (36.2%) vs non-manual (45.2%), $p = 0.01$ Women Not significant
Juneau (2014) UK	4,605 men 5,019 women	0	34	Birth (0 years) Highest parent's social class	5 years and 10 years: highest parent's social class 30 years: own social class	34 years Own social class Leisure-time physical activity (questionnaire) Physical activity at work (questionnaire) Physical activity during transports (questionnaire)	Structural equation modeling	Sex For physical activity during transports only: time required to travel from home to work, rating of local public transport services	Men Highest parent's social class at birth r for LTPA = -0.080, $p < 0.001$ Highest parent's social class at birth r for physical activity at work = 0.215, $p < 0.001$ Women Highest parent's social class at birth r for LTPA = -0.053, $p < 0.001$ Highest parent's social class at birth r for physical activity during transports = 0.076, $p < 0.001$ Highest parent's social class at birth r for physical activity at work = 0.136, $p < 0.001$
Kimm (2002) USA	1,213 black girls 1,166 white girls	9-10	18-19	9-10 years Highest parent's education Total annual household income Leisure-time physical activity (Habitual Activity Questionnaire, validated)	9 follow-ups (annually after baseline) for a total of 10 years of measurement until age 18-19 years Leisure-time physical activity (Habitual Activity Questionnaire, validated) measured for years 1, 3, 5, 7, 8, 9, and 10		Generalized-estimating-equation models	Number of parents in the household, BMI, pregnancy, smoking	Women Lowest education mother beta LTPA = -1.28, $p = 0.01$ in black girls Lowest education mother beta LTPA = -1.80, $p = 0.01$ in white girls

Kvaavik (2012)Norway	498 adults	11-15	40	11-15 yearsFather's educationMother's educationLeisure-time physical activity (questionnaire)Cardio-respiratory fitness	13-17 years: father and mother's education, LTPA (questionnaire), cardio-respiratory fitness23-27 years: own education, LTPA (questionnaire)31-35 years: own education, LTPA (questionnaire)	38-42 yearsOwn educationLeisure-time physical activity (questionnaire)	Logistic regression	Sex , intervention	Not significant
Osler (2007) Denmark	1,284 male twins 1,177 female twins	46-69		46-69 years Parental social class (measured retrospectively for childhood; aged not specified) Own or highest's household social class Own education Walking, running and biking for leisure or transport (questionnaire validated in-house by research team)			t-test for mean matched difference across twin pairs	None	Not significant
Osler (2008) Denmark	6,292 men	0	51	0 year Father's social class	18 years Own education	51 years Walking, running, and biking during leisure (questionnaire)	Logistic regression	Cognitive function, labour market participation, divorce at age 30	Not significant

Sagatun (2008) Norway	1,112 men 1,377 women	15-16	18-19	15-16 years Perceived family economy Neighbourhood socio-economic level Leisure-time physical activity (questionnaire validated by accelerometers)	17-18 years Father's social class Father's education Mother's social class Mother's education Father's income	18-19 years Perceived family economy Neighbourhood socio-economic level Leisure-time physical activity (questionnaire validated by accelerometers)	ANOVA	Sex	Men Not significant Women Mean (SD) physical activity level by father income low = 3.10 (3.09) vs medium = 3.55 (3.02) vs high = 3.83 (2.92) in ethnic Norwegian women, p for trend = 0.05 Mean (SD) physical activity level by father income low = 1.71 (2.19) vs medium = 2.00 (2.24) vs high = 3.08 (2.11) in ethnic minority women, p for trend = 0.05 Mean (SD) physical activity level by mother education low = 2.74 (2.62) vs medium = 3.55 (3.05) vs high = 3.73 (2.99) in ethnic Norwegian women, p for trends = 0.04
Salonen (2011)Finland	907 men1,060 women	0	57-70	0 yearsFather's social class	57-70 yearsOwn social classOwn educationLeisure-time physical activity (KIHD 12-month LTPA history based on Lakka et al. 1994)		Multiple regression	Sex	MenEffect size not specified as socioeconomic position during childhood was not the focus of this paper (p ≤ 0.01)WomenNot significant

Svedenkrans (2013) Sweden	218,820 men	7-17	18-26	7-17 years Highest parent's education Highest parent's social class Highest parent's income	18-26 years Cardiorespiratory fitness (cycle ergometer test)	General linear modeling	Age, gestational age, birth weight standard deviation score, number of births of the mother, maternal country of birth, maternal age, parity, own BMI, own blood pressure, own health status	Men only Adjusted Least Square Mean (95% CI) cardiorespiratory fitness by highest parent's education: unspecified 283 (279 - 287), primary/secondary <9 years 276 (272 - 280), primary/secondary 9-10 years 282 (278 - 285), upper secondary ≤2 years 285 (281 - 289), upper secondary 3 years 287 (284 - 291), post-secondary <3 years 292 (288 - 295), post-secondary 293 (290 - 297), post-graduate 292 (288 - 296), p for trend < 0.001
Taverno Ross (2014) USA	1,018 men 1,246 women	14.9 ± 1.6	25.3 ± 1.6	14.9 ± 1.6 years Leisure-time physical activity (measured by the validated Leisure Time Exercise Questionnaire) Nativity (US- or foreign-born) Highest parent's education	25.3 ± 1.6 years Leisure-time physical activity (measured by the validated Leisure Time Exercise Questionnaire)	ANCOVA	Age, race/ethnicity, highest parent's education, baseline leisure-time physical activity	Men Mean hours of MVPA (SE): foreign-born 3.4 (0.36) vs US-born 5.3 (0.16), p < 0.001 Women Not significant
Telama (2009) Finland	2,832 adults	12-18	40-46	12-18 years Father's education Leisure-time physical activity (questionnaire validated in-house by research team)	14 times over 28 years Leisure-time physical activity (questionnaire validated in-house by research team)	ANOVA	Age, sex	Men Mean hours of MVPA: low (41.1%) vs high (50.8) father education, p < 0.000 Women Mean hours of MVPA: low (30%) vs high (40.7%) father education, p < 0.000

Azevedo (2008)Brazil	2,212 men2,084 women	0	22-23	0 yearFamily income	22-23 yearsFamily incomeSkin colorLeisure-time physical activity (IPAQ)	Poisson's regression	Sex, skin color	MenLowest family income at birth PR inactive (95% CI) = 1.26 (1.00 - 1.59)Income change downward PR inactive (95% CI) = 1.32 (1.19 - 1.47)WomenLowest family income at birth PR inactive (95% CI) = 1.41 (1.22 - 1.64)Income change downward PR inactive (95% CI) = 1.14 (1.08 - 1.20)
Bell (2006) Australia	853 women	22-27		22-27 years Hours and minutes spent in walking, moderate, and vigorous activity during the last week (questionnaire, Armstrong, Bauman, and Davies, 2000) Highest parent's social class (measured retrospectively for childhood, age not specified)		ANOVA	None	Not significant
Blane (1996) UK	5,645 men	35-64		35-64 years The father's social class (measured retrospectively for childhood, age not specified) Own social class Recreational exercise such as as walking, gardening, and golf (questionnaire)		Multiple regression	Age	Not significant

Elwell-Sutton (2011) China	5,381 men 14,705 women	50+	50 years or more Parental possession of watch, sewing machine, or bicycle (measured retrospectively for childhood, age not specified) Own education (measured retrospectively for early adulthood, age not specified) Own longest-held social occupation (measured retrospectively for late adulthood, age not specified) Household income Leisure-time physical activity (IPAQ)		x2 test	None	Not significant
Heraclides (2008)UK	3,364 men1,234 women	44-69	31-54 yearsFather's social class (measured retrospectively for childhood, age not specified)	45-68 yearsOwn educationOwn social classWalking, cycling, sports, gardening activities, housework, and house maintenance physical activity (questionnaire based on the Minnesota leisure-time activity questionnaire)	Prevalence by father's social class (test not specified)	Sex	Not significant

Hillsdon (2008) UK	4,286 women	60-79	60-79 years Father's social class (measured retrospectively for childhood, age not specified) Childhood household amenities (measured retrospectively for childhood, age not specified) Family access to a car (measured retrospectively for childhood, age not specified) Age at leaving full-time education (measured retrospectively) Own social class Husband's social class Housing tenure Car ownership Pension arrangements Electoral ward geographical area Walking, cycling, heavy gardening, and physical exercise (questionnaire)	Ordinal logistic regression	Age, body mass index, smoking, and cardiovascular and respiratory disease	Women only OR of being more physically active per increase of one indicator of socioeconomic position during childhood (95% CI) = 0.94 (0.90 - 0.99)
Leino (1999) Finland	196 men 236 women	21-30	21-30 years Highest parent's education (measured retrospectively for childhood, age not specified) Own education Own employment status Exercise (questionnaire)	Multiple regression	Age, marital status, and recent unemployement	Not significant

Lynch (1997)Finland	2,682 men	42-60		42-60 yearsFather's education (measured retrospectively for age 10 years)Father's social class (measured retrospectively for age 10 years)Mother's education (measured retrospectively for age 10 years)Mother's social class (measured retrospectively for age 10 years)Family lived on a farm and farm size (measured retrospectively for age 10 years)Family perceived as wealthy (measured retrospectively for age 10 years)Own educationOwn social classOwn incomeHousing tenureJob insecurityUnemployementMaterial possessionsLeisure-time physical activity (questionnaire based on Lakka et al. 1994)		x2 test	Age	Men onlyIndex of socioeconomic conditions poor (29.9% in low quartile of PA) vs high (24% in low quartile of PA), $p < 0.05$
Øygard (1998) Norway	249 men 265 women	11-14	23-26	11-14 years Father's education Leisure-time physical activity (questionnaire)	23-26 years Own education Leisure-time physical activity (questionnaire)	x2 test	None	Not significant
Popham (2006) UK	9,473 adults	18-64		4 survey waves across 8 years Having attended a fee paying school (measure retrospectively for childhood; age not specified) Only participants aged 18-64 years at each wave Own education Own employment status Own social class Leisure-time physical activity (questionnaire)		Logistic random effects regression modelling	Age, year of interview, health, smoking	Men Not significant Women Having attended a fee paying school OR participation in weekly leisure-time exercise (CI% 95) = 1.37 (1.04 - 1.81)

Pudrovska (2012) USA	2,615 men 3,163 women	17-18	64-65	17-18 years Father's education Mother's education Family income Father's occupation Occupational education (proportion of individuals in a given occupation who completed one or more years of college) Occupational income (proportion of individuals in a given occupation who earned more than US$10,000) Sports participation in high school	53-54 years Own education Own social class Household wealth Occupational education Occupational income	64-65 Light exercise (interview) Vigorous exercise (interview)	Structural equation modeling	Self-rated health, physical symptoms, chronic illnesses, BMI, depressive symptoms, marital status, parental status, smoking, alcohol use	Total effect (beta) of socioeconomic status at age 17-18 years = 1.117, $p < 0.001$ (similar for men and women)
Regidor (2004)Spain	1,660 men1,987 women	60+		Over 60 yearsFather's social class (measured retrospectively for childhood; age not specified)Own social classLeisure-time physical activity (questionnaire)			Binomial regression	Age, sex	MenNot significantWomenPrevalence ratio (95% CI) of physical inactivity for lowest vs highest father social class = 1.28 (1.05 - 1.55)
Salonna (2008) Slovakia	361 men 483 women	14-15	18-19	14-15 years Own education Highest parent's education Highest parent's social class Sport (questionnaire)	18-19 years Own employment status Sport (questionnaire)		Logistic regression	Age, sex	Men Not significant Women Low vs high highest parent's education OR (95% CI) insufficient physical activity 2.15 (1.25 - 4.71) (medium) Low vs high highest parent's social class OR (95% CI) insufficient physical activity 1.83 (1.13 - 2.97)

Tammelin (2003) Finland	3,069 men 3,600 women	14	31	14 years Father's social class Sport (questionnaire)	31 years Own education Employment status Place of residence Leisure-time physical activity (questionnaire)	Logistic regression	Sport participation at 14 years	Not significant
Van de Mheen (1998) Netherlands	13,854 adults	25-74		25-74 years Father's social class (measured retrospectively for childhood for age 12 years) Own social class Leisure-time physical activity (questionnaire)		Logistic regression	Age, sex, marital status, religious affiliation, degree of urbanization	Men Not significant Women OR of frequent physical activity 0.68 when unskilled father social class vs high professional
Bowen (2010) USA	18,465 adults	50+		Over 50 years Father and mother's education (measured retrospectively for childhood, age not specified) Father occupation (measured retrospectively for age 16 years) Own education Own income Own wealth Physical labor on the job, heavy housework, aerobics, bicycling, running/jogging, and swimming (questionnaire; Wilson et al. 1998)		t-test	None	Men and women combined Mother education low (0.19) vs high (0.23), $p < 0.001$ Father education low (0.19) vs high (0.23), $p < 0.001$ Father social class manual (0.19) vs non manual (0.25), $p < 0.001$
Heslop (2001)UK	958 women	35-64Not specified in article; found in Blane et al. 1996		35-64 yearsFather's social class (measured retrospectively for childhood, age not specified)Own social classOwn educationGeographical area deprivationRecreational exercise such as as walking, gardening, and golf (questionnaire)		ANOVA	Age	Not significant

Suppli (2013) Denmark	215 men 346 women	15	27	15 years Weekly hours of vigorous physical activity Father's and mother's occupation (measured retrospectively for parental age 50 years)	19 years Weekly hours of vigorous physical activity	27 years Weekly hours of vigorous physical activity Father's and mother's occupation (measured retrospectively for parental age 50 years)	Stratified logistic regression	Sex	Men and women combined None reported (although subgroup analyses showed interaction)
Kamphuis (2013) Netherlands	4,894 men	40-75		40-75 years Father's social class (measured retrospectively for age 12 years) Own education Leisure-time physical activity (questionnaire) Sports (questionnaire) Physical activity during transport (questionnaire)			x2 test	Men only	Not significant
Kittleson (2006) USA	1,131 men	26		26 years Father's social class (measured retrospectively for childhood, age not specified) Physical training (questionnaire)			x2 test	None	Not significant
Ramsay (2007) UK	5,188 men	52-73		52-73 years Father's social class (measured retrospectively for childhood; longest held occupation) Household amenities (measured retrospectively for 0-10 years) Own social class Leisure-time and transport-related physical activity (questionnaire)			t-test	None	Men only Father social class manual (74% inactive) vs non-manual (26% inactive), p = 0.05

Studies are ordered by quality score. *For prospective studies only.

5.2 — Critical review of methodological limitations

Life course epidemiology is a relatively new area of research, as is research linking socioeconomic position during childhood and physical activity during adulthood. This body of research consists mostly of observational studies, which are generally regarded as producing evidence of lower quality than randomized controlled trials. We aimed to highlight a set of common limitations found in this body of literature and to make specific recommendations to strengthen methodology. This critical review answers this thesis' second objective (see section 3): " To review the methodological limitations most commonly found in this body of literature and to make recommendations to strengthen future research."

Nine important limitations were found repeatedly in the literature we have just reviewed on socioeconomic position during childhood and physical activity during adulthood. We will expand on these limitations here. In many studies, we have found that: (1) different indicators of socioeconomic position were used at different points in time over the life course; (2) socioeconomic position during childhood was assessed retrospectively, during adulthood; (3) socioeconomic position during adulthood was not controlled for, or included in the statistical analysis; (4) cross-sectional designs were used; (5) variables were measured for only two points in time over the life course; (6) authors did not specify for what age childhood socioeconomic conditions were measured (7) non valid measures of physical activity were used; (8) leisure-time physical activity was the only outcome; and (9) the statistical methods used did not translate into practice the full richness of life course epidemiology theory.

5.2.1 — Different indicators of socioeconomic status at different points in time

In the literature on life course socioeconomic position and physical activity, different indicators of socioeconomic position have been used interchangeably, sometimes within the same study, without regard to the unique dimension of socioeconomic position they reflect.

Among the 42 studies that were included in our systematic review, 34 assessed socioeconomic position at least twice. Of those, eight (23.5%) combined different indicators of socioeconomic position at different points in time over the life course in the same analysis (Aarnio et al., 2002; Huurre et al., 2003; Sagatun et al., 2008; Osler et al., 2008; Elwell-Sutton et al., 2011; Salonna et al., 2008; Tammelin et al., 2003; Kamphuis et al., 2013). The combination most commonly used was parental social class as an indicator of socioeconomic position during childhood and own education as an indicator of socioeconomic position during adulthood. This combination was used in five of the eight studies that combined different indicators of socioeconomic position at different points in time over the life course in the same analysis (Aarnio et al., 2002; Huurre et al., 2003; Osler et al., 2008; Tammelin et al., 2003; Kamphuis et al., 2013). A more valid approach would be to study the association of the same indicator throughout the life course in order to describe more accurately how and, eventually, understand why each dimension of socioeconomic position is associated with physical activity during adulthood. Also, by studying each indicator separately, as the evidence base grows, it will be possible to compare the strength of their association and, perhaps, identify priorities for intervention. Few studies have done this so far. These analyses would provide additional insights into the relative importance of each indicator and could highlight new avenues for research exploring their causal pathways.

5.2.2 — Retrospective measurement of socioeconomic status for childhood

In a review, Hardt and Rutter (2004) concluded that retrospective report in adulthood of adverse experiences in childhood involves substantial measurement error and recall bias. Their review of 14 studies was published in the *Journal of Child Psychology and Psychiatry* and focused on sexual abuse, physical abuse, physical/emotional neglect, and family discord during childhood. Therefore, their findings may not apply wholly to life course socioeconomic position research.

Validity studies of retrospective recall of socioeconomic position during childhood are more scarce (no review on this topic were found). Berney and Blane (1997) collected information from 57 UK subjects aged 64 to 83 years and compared it with archive material of the same subjects' social circumstances recorded 50 years previously. Their sample comprised subjects from two historical cohorts: the Mass Observation cohort and the Boyd Orr cohort. In the Mass Observation cohort, 80% of subjects recalled their father's occupation correctly, while only 66% of subjects in the Boyd Orr cohort did so. In the Boyd Orr cohort, information about access to domestic water facilities was recalled correctly by 94% of subjects. Information about toilet facilities was recalled with 100% accuracy. Recall of domestic facilities thus seems more accurate than recall of socioeconomic position, although this measure is likely to be less useful for younger cohorts that grew up in times when water and toilet facilities were most widespread.

Krieger et al. (1998) conducted a cross-sectional study of 352 adult women twin pairs in California. Among twin pairs, 91% (95% Cl: 89-94%) agreed on their father's educational level and 80% (95% Cl: 76-84%) agreed on their childhood social class. Childhood social class was measured for age 14 years, and was defined as an ordinal variable with four categories related to the head-of-household: self-employed/owner of business; supervisory employee; non-supervisory employee; not in paid work force. In this study, the father's education level was recalled with greater reliability (between twins) than the father's social class. Reliability of recall of the father's social class approached that observed in Berney and Blane's study (1997) of historical records. A noteworthy difference should be pointed out: while Berney and Blane's study (1997) of historical records can be considered a study of validity of recall, Krieger et al.'s study (1998) of twins would be more accurately considered a study of reliability (between twins), as the father's true education level or social class was not verified.

Batty et al. (2005) analyzed data from the Aberdeen children of the 1950s study, a cohort of 12 150 people born in Aberdeen (Scotland) who took part in a school based survey in 1962. In this survey, information was collected about the father's occupation at birth (reported by the mother at birth) and the father's occupation during childhood (reported in 1962 at age 6-12 years by children). Data from both time points were classified into six categories according to a schema resembling the 1950 Registrar General's classification: I—professional; II—managerial; IIINM—nonmanual, skilled non-manual; IIIM—manual, skilled manual; IV—manual, semi-skilled; and V—unskilled manual. Between 2000 and 2003, a questionnaire was mailed to traced middle aged cohort members. A total of 7,183 (63.7%) persons responded to the mid-life questionnaire, which included questions about their father's occupation during their childhood. Data from the mid-life questionnaire showed that subjects recalled their father's occupation at birth correctly in 53.7% of cases, and that of their father during their childhood (at age 6-12 years) in 61.4% of cases. Additional analyses were carried out using weighted k statistics (Landis and Koch, 1977). Weighted k scores were 0.47, $P < 0.001$ (for agreement between adult recall and historical records of father's occupation at birth) and 0.56, $P < 0.001$ (for agreement between adult recall and historical records of father's occupation at age 6-12 years), suggesting a moderate level of agreement in both cases (k statistic values of ≥ 0.61 indicate substantial agreement; 0.41–0.60 indicate moderate agreement, and ≤ 0.40 indicate low agreement). Thus, in this study, accuracy of recall was lower than in Berney and Blane's (1997) similar study of historical records, also carried out in the UK.

Kauhanen et al. (2006) presented data suggesting that analyses based on retrospective recall underestimate the true impact of socioeconomic position during childhood. Their study examined the association between a socially disadvantaged childhood and all-cause mortality, cardiovascular disease mortality, coronary heart disease mortality, and acute coronary events. They used data from the Kuopio Ischemic Heart Disease Risk Factor Study (eastern Finland). They carried out two sets of analyses. For the first set, exposure was based on historical records (n=698). For the second set of analyses, the same associations were estimated with exposure based on retrospective recall (n=2,682). In models using historical records data and fully adjusted for socioeconomic position during adulthood as well as biological and behavioral risk factors, associations were 1.33 (0.92-1.92), 1.42 (0.85-2.38), 1.64 (0.91-2.99), and 1.63 (1.09-2.44) for all-cause mortality, cardiovascular disease mortality, coronary heart disease mortality, and acute coronary events, respectively. In analogous models using retrospective recall data, associations were 0.89 (0.75-1.06), 0.79 (0.61-1.02), 0.84 (0.62-1.13), and 0.97 (0.82-1.19), respectively. Associations were thus weaker and became non significant (for acute coronary events) when retrospective recall data was used. The authors concluded that: "The results of this study support the concept that using recalled information of childhood circumstances may underestimate the true impact of childhood socioeconomic situation." Unfortunately, they did not examine agreement between retrospective recall and historical records.

Overall, these studies indicate that: (1) retrospective recall of social class during childhood is moderately valid, with agreement ranging from 53.7% to 80%; (2) retrospective recall of socioeconomic position based on domestic facilities is more valid (94-100% accuracy); (3) reliability of recall (based on twins' agreement) is high (91% for educational level and 80% for social class); (4) analyses based on retrospective recall underestimate the true impact of socioeconomic position during childhood. Of the 42 studies included in our systematic review, only 23 (54.8%) assessed childhood socioeconomic position prospectively during childhood. The remainder measured it during adulthood using retrospective recall. The evidence we have reviewed here suggests that these studies' results should be interpreted with caution.

5.2.3 — No control for socioeconomic position during adulthood

Statistical models of socioeconomic position during childhood and physical activity during adulthood should include a variable for socioeconomic position during adulthood. This variable should be included as an independent, interacting, mediating, or confounding variable, based on the conceptual model of the authors. This argument has a conceptual and an empirical basis. From a conceptual standpoint, in the life course framework, childhood and adulthood are not separate, mutually exclusive stages of human development. To the contrary, adulthood is seen as the continuity of childhood. Thus, the potential influence of life experiences during childhood on health or behaviour during adulthood cannot be studied without regard to the expression of these life experiences during adulthood, and vice versa. From an empirical standpoint, socioeconomic position during adulthood is associated with physical activity during adulthood. This cross-sectional association is well established (Gidlow et al., 2006). Therefore, any association between past socioeconomic status and physical activity during adulthood unadjusted for concurrent socioeconomic status may be an artifact of the tracking of past socioeconomic status into adulthood (Corcoran, 1995).

5.2.4 — Cross-sectional design

Cross-sectional designs limit causal inference because exposure and outcome are measured at the same point in time. A key criterion for causal inference is temporality (Hill, 1965; Susser, 1991). Temporality states that cause must precede effect. In cross-sectional designs, this criterion cannot be ensured. While retrospective measurement gives an idea of temporality, this criterion is only really respected when a prospective study design is used. A prospective study design has been used in 23 of the 42 studies we have reviewed (54.8%). The others used a cross-sectional design, limiting causal inference. Should attempts be made to draw definitive conclusions from this body of literature regarding causal inference, evidence from prospective cohort studies will provide stronger support.

5.2.5 — Measurement for only two points in time

Closely related to the problem of not including socioeconomic position during adulthood in the statistical analysis is the limitation of assessing socioeconomic position for only two points in time. This is an important limitation from both a theoretical standpoint and a methodological standpoint.

From a theoretical standpoint, measuring socioeconomic position for only two points in time overly simplifies the life course. According to life course epidemiology theory, the life course is a continuous process, with health at each point in time the result of all the exposures experienced hitherto. Some exposures may be long-lasting. Some may be acute. Their effects may be measured immediately or after a few months; other effects may not be fully measured until old age. For example, a lifetime of low socioeconomic position, smoking, physical inactivity, and poor diet is most likely to increase risk of cardiovascular disease; however, cardiovascular disease may not develop until old age. In addition, if socioeconomic position is assessed first during adolescence, childhood will be missed as a potential sensitive period (Galobardes et al., 2006). Moreover, strength of association between exposure and outcome may change over time. It also may change according to the age at which exposure and outcome were measured. These nuances are lost when the life course is reduced to measurement at only two points in time. This is why, from a theoretical standpoint, measurement at multiple points across the life course is preferable.

From a methodological standpoint, measuring socioeconomic position for only two points in time is a limitation because it precludes careful examination for critical periods and accumulation of risk. For example, some evidence suggests that childhood and adolescence may be sensitive periods for physical activity during adulthood. This evidence is based on the literature on fundamental movement skills, which we have presented in section 1. As we have seen, fundamental movement skills, are "considered to be the building blocks that lead to specialized movement sequences required for adequate participation in many organized and non-organized physical activities for children, adolescents and adults" (Lubans et al., 2010).

Briefly, according to this literature, early childhood and adolescence may both be sensitive periods for physical activity later in life (because fundamental movement skills are learned during early childhood and because they are refined into specialized movement sequences during adolescence). Are childhood and adolescence both sensitive periods? Is one more sensitive than the other? If any one is, at what age specifically should public health officials intervene? These questions cannot be answered if socioeconomic conditions are assessed only once during childhood. At best, assessing socioeconomic position once during childhood gives an indication of whether it is associated with physical activity during adulthood. What it gives no indication of, however, is whether childhood or adolescence is a more sensitive period, and a what age specifically public health officials should intervene for maximum impact.

To answer these questions, socioeconomic position and physical activity should be measured multiple times during childhood, ideally starting at birth and at close intervals until age 18 years. Under conditions less than ideal, for examination of sensitive periods, socioeconomic position (and, if possible, physical activity) should be measured at least once during childhood and once during adolescence.

The same reasoning holds true for examination of accumulation of risk. While crude analyses of accumulation of risk can be performed when exposure is measured for only two points of the life course, a more detailed (and, likely, a more accurate) picture of accumulation of risk can be obtained when exposure is measured at multiple points throughout the life course.

With notable exceptions (Aarnio et al., 2002; Osler et al. 2008; Sagatun et al., 2008 Silverwood et al. 2012; Lynch et al., 1997; Telama et al. 2009; Elwell-Sutton et al. 2011; Pudrovska and Anishkin, 2012; Suppli et al., 2013; Juneau et al., 2014), in the studies we have reviewed, the life course has been operationalized as only two points in time. Of the 42 studies we have reviewed, 32 operationalized the life course as two points in time, eight operationalized the life course as three points in time (Aarnio et al., 2002; Osler et al. 2008; Sagatun et al., 2008; Silverwood et al. 2012; Lynch et al., 1997; Elwell-Sutton et al. 2011; Pudrovska and Anishkin, 2012; Suppli et al., 2013), one study operationalized the life course as five points in time (Juneau et al., 2014), and one study operationalized the life course as 14 measurement points over 28 years (Telama et al. 2009).

5.2.6 — Failure to specify for what age during childhood socioeconomic position was measured

As we have just seen, fundamental movement skills are learned early in life, mastered during childhood, and refined into specialized movement sequences during adolescence. Any of these stages of motor development may be a sensitive period for physical activity during adulthood. If life course epidemiology researchers hypothesize that low social position during childhood decreases physical activity during adulthood (perhaps by slowing down acquisition of fundamental movement skills and motor development), they should be very specific about the age at which social position during childhood is measured, as the mechanism through which low social position potentially decreases physical activity during adulthood is likely to be different for early life, childhood, and adolescence.

Unfortunately, not all studies we have reviewed have reported for what age exactly socioeconomic position during childhood was measured. Of the 42 studies we have reviewed, 13 (31%) did not report this information. In all 13 cases, socioeconomic position during childhood was measured retrospectively, sometimes well into old age. Because so many years have elapsed since childhood for these study participants, it is less likely they would remember their socioeconomic position accurately for a specific age; the authors of the these studies may have wanted to circumvent this limitation by asking participants to report their socioeconomic position generally for childhood. Nonetheless, this is an important limitation that precludes examination for sensitive periods. Such examinations are needed to fully understand the nature of the relationship between socioeconomic position during childhood and physical activity during adulthood.

5.2.7 — Non valid measures of physical activity

To reduce misclassification bias, physical activity needs to be measured using validated instruments that have been shown to be valid and reliable. Misclassification bias occurs when physically inactive subjects are labeled as active and vice versa. This bias can spuriously increase or decrease the observed strength of an association (Jurek et al., 2005), reducing internal validity.

We have noted previously that questionnaires are a poor measure of physical activity. In our sample of 42 studies examining the association between socioeconomic position during childhood and physical activity during adulthood, 40 (95.2%) used questionnaires to assess physical activity (only two studies used another measure: cardiorespiratory fitness). Of the 40 studies that used questionnaires, 22 (55%) used unvalidated questionnaires. Since their validity and reliability is unknown, their results should be interpreted with much caution. The other 18 studies (45%) used validated questionnaires. Validated questionnaires are a step in the right direction, but as we have seen, they are still prone to significant measurement error (Prince et al., 2008; Lee et al., 2011). Thus, care should be used when interpreting questionnaire-based physical activity data from large-scale epidemiological studies, even when validated questionnaire are used.

5.2.8 — Leisure-time physical activity was the only outcome

Physical activity can be measured in four domains of life: during leisure time, at work, at home, and during transports (Bauman et al., 2006). Leisure-time physical activity includes organized activity such as team or individual sport, walking groups, and gym classes. It also includes non organized, recreational sport and walking for exercise (Bauman et al., 2006). Physical activity at work or "occupational physical activity" includes all work-related energy expenditure (Bauman et al., 2006). Physical activity at home (also sometimes called "housework" or "domestic" physical activity) includes do-it-yourself repairs, gardening, house cleaning, and child care (Lawlor et al., 2002; Bauman et al., 2006). Physical activity during transports include all forms of physically active transportation, such as walking and cycling, to get to and from places (Bauman et al., 2006).

Physical activity in all domains of life has the potential to enhance health and to prevent premature mortality (Samitz et al., 2011). Indeed, one of the very first studies linking physical activity to health was carried out in a work setting (Morris et al., 1953). More recently, Samitz et al. (2011) conducted a systematic review and meta-analysis to determine the association with all-cause mortality of different domains of physical activity. Data from 80 studies with 1,338,143 participants was used to estimate combined risk ratios using random-effects models. Combined risk ratios comparing highest with lowest physical activity levels were 0.65 (95% CI 0.60–0.71) for total physical activity, 0.74 (95% CI 0.70–0.77) for leisure-time physical activity, 0.64 (95% CI 0.55–0.75) for activities of daily living (including housework and gardening), 0.88 (95% CI 0.79-0.98) for physical activity during transports, and 0.83 (95% CI 0.71–0.97) for occupational physical activity. The authors concluded that "Higher levels of total and domain-specific physical activity were associated with reduced all-cause mortality" (Samitz et al., 2011). Thus, physical activity in all domains of life can prevent premature mortality, and not just physical activity during leisure time.

Traditionally, public health guidelines have focused on exercise, promoting increased physical activity during leisure time (ACSM, 1978; ACSM 1990; U.S. Office of the Surgeon General, 1996; Blair et al., 2004). More recent guidelines encourage people to be active in all domains of life, and not just during their leisure time (U.S. Office of the Surgeon General, 1996; Haskell et al., 2007; U.S. Department of Health and Human Services, 2008; World Health Organization, 2010; Canadian Society for Exercise Physiology, 2011). For example, the latest Canadian guidelines (150 minutes a week) mention that "Adults can meet these guidelines through planned exercise sessions, transportation, recreation, sports, or occupational demands, in the context of family, work, volunteer, and community activities (Canadian Society for Exercise Physiology, 2011).

This historical focus on leisure-time physical activity is also found in the studies we have systematically reviewed. Overall, in the 42 studies we have reviewed, 30 studies had only one outcome for physical activity; 12 had multiple. Leisure-time physical activity was by far the most commonly reported outcome, with 33 studies including at least one measure of physical activity during leisure time. Physical activity during transports was the second most commonly reported outcome, with only 6 studies reporting physical activity during transports. This illustrates how focused on leisure-time physical activity this body of literature is.

This is a limitation, because physical activity levels in all four domains of life are correlated with each other (Rovniak et al., 2010) and with socioeconomic position (Beenackers et al., 2012). Therefore, studies that have only measured physical activity during leisure time are missing three potential unmeasured confounders (physical activity at work, at home, and during transports). Their results should be interpreted with caution. Moreover, their conclusions are restricted to leisure-time physical activity and should not be generalized to overall, whole-day physical activity (which includes physical activity in other domains of life).

5.2.9 — The statistical methods used did not translate into practice the full richness of life course epidemiology theory

There is a gap between theory and practice in the epidemiological literature on life course social position and physical activity. On the one hand, life course epidemiology theory proposes that the life course is a continuous process. In this process, health at any age is the product of determinants in the present, as well as of determinants in the past, going as far back as fetal development. According to theory, determinants early in life may influence health during adulthood directly (an independent effect) or indirectly through determinants during adulthood (an effect that is mediated).

Theoretical models that hypothesize that determinants early in life influence health during adulthood indirectly through determinants during adulthood (mediation) fall into the category of "accumulation of risk." Theoretical models hypothesizing that this is the only influence of past determinants (mediation only) are models of "accumulation of risk with trigger effect." Theoretical models that hypothesize that determinants early in life may also influence health during adulthood directly (independent effect plus mediation) are models of "accumulation of risk with additive effects." Finally, theoretical models that hypothesize that determinants early in life influence health during adulthood directly with no influence of determinants during adulthood (independent effect only) fall into the category of "critical period" models. Critical period models would also include models that hypothesize an independent effect of determinants during adolescence, with no influence of determinants earlier (during childhood) or later (during adulthood) in life.

To capture fully the richness of these theoretical models, data must be analyzed using a statistical technique that estimates (1) the direct association between past determinants and health outcomes in the present (potential independent effect) and (2) their indirect association through determinants in the present (mediation). In other words, if we want our statistical analysis of life course data to stay true to life course epidemiology theory, we must use statistical methods that estimate (1) the independent, direct association of determinants at each point of the life course with our outcome and (2) their indirect association through other determinants, or through the same determinants later in life. By using statistical techniques that do not estimate indirect associations, researchers in this field of study have failed to translate into practice the full richness of life course epidemiology theory.

There is another important limitation concerning the statistical techniques commonly used in this body of literature. These techniques are limited with regards to life course epidemiology theory because they do not allow competing models to be evaluated and tested, with a decisive winner based on statistical indices, a formal statistical test, and a p value. Structural equation modeling is a technique that provides information about model fit based on statistical indices, a formal statistical test, and a p value, but it has not yet been used in this literature. Structural equation modeling can be used to assess how each life course model fits the data, and statistical tests of goodness of fit and p values can be used to compare competing models and determine a winner based on model fit.

In our paper titled "Structural equation modeling for life course epidemiology: benefits and example" (see section 5), we have described our use of structural equation modeling applied to life course data, also called of "life course path analysis." Not only this technique estimates indirect and direct associations, but it also provides statistical indices, a formal statistical test, and a p value for model fit, allowing researchers in life course epidemiology to determine which life course models best represents the associations they are studying. In our paper, we also aimed to advance the practice of epidemiology by proposing a new terminology for independent variables in life course path analysis models. In a life course path analysis, the same independent variable measured multiple times across the life course acts as its own predictor and outcome: measures at each point in time are predicted by the previous measure and predict the next. We referred to this as the "independent variable path". Examination of coefficients between measures along the independent variable path and between each measure and the outcome can provide a fine-grained analysis of the life course association between these variables. This paper is the third and final original contribution of this thesis, and it is found in the following section.

5.3 — Original Research

We have just highlighted nine methodological limitations commonly found in the literature on socioeconomic position during childhood and physical activity during adulthood. We have also made recommendations to strengthen future research. This thesis' second objective was to apply these recommendations in our own original research. The following two original contributions answer this objective.

Notably, our critical review has underscored that regression-based techniques such as logistic and multiple regression share a common set of limitations that create a gap between theory and methods when they are used to analyze life course data. We have argued that structural equation modeling can bridge that gap, in particular by helping to select among competing theoretical models when analyzing life course data. Therefore, a secondary goal of our original research became to contribute to bridging the gap between theory and methods in life course epidemiology, by showing that structural equation modeling can be a helpful tool in selecting among competing theoretical models when analyzing life course data.

In analyzing life course data on socioeconomic position and physical activity, we aimed to illustrate three benefits of structural equation modeling over traditional regression-based techniques, namely: 1) all associations between any number of variables in the model can be estimated at once; 2) indirect associations can be estimated; 3) competing models can be compared based on goodness of fit statistics and a formal test of significance (for nested models).

Other strengths of our original contributions include: the same indicator was used to assess socioeconomic position throughout the life course (social class for the UK dataset, education and income for the Canadian dataset), childhood socioeconomic position was assessed during childhood in a prospective study design (both datasets), socioeconomic position during adulthood was included in the statistical analysis (both datasets), socioeconomic position was measured at multiple points in time (5 points in the UK dataset, 3 points in the Canadian dataset), childhood socioeconomic position was measured for a specific age (both datasets), physical activity was examined for multiple domains of life (work, leisure, and transports in the UK dataset, leisure only in the Canadian dataset), and structural equation modeling was used to analyze the life course data, helping to translate into practice the full conceptual richness of life course epidemiology theory (both datasets).

The only methodological limitation we have not been able to improve upon was "non valid measures of physical activity." Indeed, in both cohorts, physical activity has been self-reported by questionnaire. In addition, the questions used in these cohorts to measure physical activity have not been validated. This is a common limitation in this body of literature and our own research shares this limitation, unfortunately.

5.3.1 — Social class across the life course and physical activity at age 34 years in the 1970 British birth cohort

This paper is the first original contribution of this thesis. It reports on the UK dataset, and it has been published in *Annals of Epidemiology* (Juneau et al., 2014). It is reproduced in full in appendix 2, with permission of Elsevier. Authors' contributions are as follows: Carl-Etienne Juneau, Alice Sullivan, Sylvana Côté, and Louise Potvin contributed to study design, planning, and interpretation of the data. Carl-Etienne Juneau, Brian Dodgeon, and George Ploubidis contributed to data assembly and analysis. Carl-Etienne Juneau wrote the manuscript. All authors commented on earlier drafts and gave their final approval of the version to be published.

Life course social class and physical activity at age 34 years in the 1970 British birth cohort

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Life course social class and physical activity at age 34 years in the 1970 British birth cohort

Abstract (184 words)

Purpose To examine the associations between social class at ages 0, 5, 10, 30, and 34 years and physical activity at age 34 years using a novel approach to analysis of life course data.

Methods We used structural equation modeling to compare three competing models in life course epidemiology: the accumulation of risk model with additive effects, the accumulation of risk model with trigger effect, and the critical period model. Data were from a nationally representative, prospective cohort of 16,571 British men and women born in 1970. Outcomes were physical activity during leisure time, during transports, and at work.

Results For all three domains of physical activity, for men and women, the accumulation of risk model with additive effects fit the data best. In this model, social class at ages 0, 5, 10, 30, and 34 years were associated with physical activity at age 34 years, although the magnitude and the direction of the associations for social class at each age varied by physical activity outcome and by sex.

Conclusions Structural equation modeling appears to be a helpful tool in selecting among competing models in life course epidemiology.

MESH HEADING KEYWORDS

Health, Public Health, Epidemiology, Exercise, Longitudinal Studies, Social Class

INTRODUCTION

A growing body of evidence suggests that poor socioeconomic conditions across the life course act cumulatively to increase risk of cardiovascular diseases. Physical inactivity is a key cardiovascular risk factor, and its association with socioeconomic conditions across the life course has also been the focus of numerous studies [1-24]. Overall, 13 studies [1-13] have found a statistically significant association between socioeconomic conditions during childhood or adolescence and physical activity in adulthood; 11 have not [14-24]. Drawing on research into life course epidemiology and social inequalities in health, this body of literature has tended to focus on low socioeconomic conditions during childhood as the main causal variable, leisure-time physical activity during adulthood as the main outcome, and socioeconomic conditions during adulthood as either a confounding, intermediate, or interacting variable.

These studies' conflicting results may be explained by a common set of limitations we aimed to address in this paper: different indicators of socioeconomic conditions have been used interchangeably across the life course (sometimes within the same study) [5, 6, 17, 19, 21], socioeconomic conditions during childhood were often measured retrospectively in cross-sectional designs [4, 6, 8, 9, 11, 12, 14, 18, 22, 24], the ages at which socioeconomic conditions were measured varied widely [1-24], and socioeconomic conditions during adulthood were not always accounted for [2, 3, 7, 8, 13, 14, 17]. Moreover, the life course has been operationalized in most studies as only two points in time (one measurement during childhood and one during adulthood) [1-4, 8-24]. Lastly, most studies focused on leisure-time physical activity [1, 2-4, 6-9, 11-17, 19-24]. Physical activity in other domains of life, such as physical activity during transports or at work, was rarely considered.

This study aimed to address these limitations and to determine how social class across the life course is associated with physical activity during adulthood. Specifically, it aimed to integrate structural equation modeling with life course epidemiology theory to determine which life course model best explains the association between life course social class and physical activity during adulthood. Three life course models were compared: the accumulation of risk model with additive effects, the accumulation of risk model with trigger effect, and the critical period model [25]. Briefly, in the accumulation of risk model with additive effects, each exposure increases risk of exposure in the subsequent period and has an independent effect on the outcome (e.g. a lifelong of smoking). In the accumulation of risk model with trigger effect, each exposure increases risk of exposure during the subsequent period, but only the last exposure triggers the outcome (e.g. injection drug use increasing risk of needle sharing and HIV transmission). In the critical period model, exposure occurring during a period where susceptibility is greater has long-lasting and unalterable effects on the outcome (e.g. prenatal drug exposure). Based on evidence of modest association with socioeconomic conditions during adulthood and weak or inconsistent association with socioeconomic conditions during childhood, we hypothesized the accumulation of risk model with additive effects would best represent the association between social class across the life course and physical activity during adulthood.

METHODS

Study design, setting, and participants

Data were from the 1970 British birth cohort (*n*=16,571), a large, ongoing, nationally representative multidisciplinary cohort study. Data were collected at birth and subjects were followed up successfully four times, at ages 5, 10, 30, and 34 years. Sample sizes (and response rates) at each follow-up were, respectively, 12,981 (78.34%), 14,350 (86.60%), 10,833 (65.37%), and 9,665 (58.32%). In 1970 (at birth), data were collected using clinical records, interviews with parents, and a questionnaire completed by the attending midwife. In 1975 (age 5 years) and 1980 (age 10 years), information was gathered from children, their parents, and school teachers. In 1999/2000 (age 30 years) and in 2004/2005 (age 34 years), subjects answered questions about all major domains of life during face-to-face interviews. Ethical approval has been granted by the UK Medical Research Ethics Council prior to each data collection cycle of the 1970 British birth cohort.

Variables and measurement

Independent variables were social class at birth and at ages 5, 10, 30, and 34 years. Occupation, a measure of social class, was self-reported by parents during interviews at birth and when subjects were aged 5 years and 10 years. Occupation was also self-reported by subjects at ages 30 years and 34 years during face-to-face interviews. For birth and ages 5 and 10 years, the highest parent's occupation was used as proxy. Occupations were categorized according to the Registrar General's classification into grades I (professional) to V (unskilled). At all ages, less than 2.6% of cases were from social class V (unskilled).

Therefore, social classes IV (partly skilled) and V (unskilled) were merged. As grade III (skilled) is split into manual and non-manual, occupation was thus a categorical variable with five ordered categories. Dependent variables were physical activity during leisure time, physical activity at work, and physical activity during transports. All were self-reported by subjects during interviews at age 34 years. For physical activity during leisure time and physical activity at work, a score representing eight weeks of habitual physical activity was computed based on answers to three questions (for leisure-time physical activity) and two questions (for physical activity at work) (Online Resource 1). These scores approximated energy expenditure: the higher the score, the more physically active the subjects were and the more energy they expended during leisure time or at work. Both scores were positively skewed and had a mode of 0. They were used separately as the dependent variable for physical activity during leisure time and physical activity at work, and zero-inflated Poisson models were used to account for the large number of zeros and positive skewness. Physical activity during transport was based on a single question about main form of transport. Subjects were asked: “What is your main form of transport?” Answers were: “car/motorcycle/moped”, “public transport (i.e. buses and trains)”, “cycling”, “walking”, “other”, or “never goes out”. Public transport was considered an active form of transport. Answers were recoded into “active” (public transport, cycling, or walking), “inactive” (car/motorcycle/moped), or “missing” (other, don't know, never goes out, or not applicable). Therefore, main form of transport was a dichotomous variable (“active” or “inactive”). Sex was a dichotomous variable (“male” or “female”). It was a confounder, and all analyses were stratified by sex. Other confounders (for physical activity during transports only) were "Time required to travel from home to work" (a categorical variable with eight ordered categories ranging from "under 5 minutes" to "2 or more hours") and "Rating of local public transport services" (a categorical variable with five ordered categories ranging from "very good" to "very poor").

Statistical methods

Prior to analysis, all variables were examined for accuracy of data entry, missing values, and fit between their distributions and the assumptions of multivariate analysis [26]. Social class at age 34 years was missing for 1,709 cases (17.8% of the sample). These were mostly “looking after home/family” (975 cases), “permanently sick/disabled” (228 cases), or “unemployed and seeking work” (193 cases). Similarly, social class was missing for 23.4%, 14.9%, 20.3%, and 9.2% of the sample at ages 30, 10, 5, and 0 years, respectively. At age 34 years, leisure-time physical activity was missing for 32 cases (0.3% of the sample), physical activity during transports was missing for 106 cases (1.1% of the sample), and physical activity at work was missing for 1,657 cases (17.2% of the sample). Missing data was imputed using full information maximum likelihood (FIML). A total of 41 outliers were detected in the sample. Outliers moved from social class IV-V to social class I between ages 30 years and 34 years, or reported being in social class I with no education. They were deleted. This left 9,624 subjects in the sample (4,605 men and 5,019 women).

Descriptive statistics were obtained using SPSS 18 (SPSS Inc, IL, USA). Bivariate correlations among social class at ages 0, 5, 10, 30, and 34 years and physical activity were computed using Spearman's rho. Analyses were stratified by sex. For each sex and each physical activity outcome, three models were compared: the accumulation of risk model with additive effects (Figure 1), the accumulation of risk model with trigger effect (Figure 2), and the critical period model (Figure 3). Structural equation models were computed using MPLUS 6.11 (Muthen & Muthen, CA, USA). Each model was run separately with physical activity during leisure time, during transport, or at work as the dependent variable. These three outcomes have all been shown to be associated with socioeconomic conditions [27]. Therefore, they were all considered to be potential confounders. As such, the model with leisure-time physical activity as the outcome was adjusted for physical activity during transports and physical activity at work. The other two models were similarly adjusted. In addition, the model with physical activity during transports as the outcome was adjusted for two more potential confounders: "time required to travel from home to work" and "rating of local public transport services". To improve missing data imputation with FIML, for all estimations, the mean of each covariate was added (these were not included in the tested models).

Model 1 – Accumulation of risk with additive effects

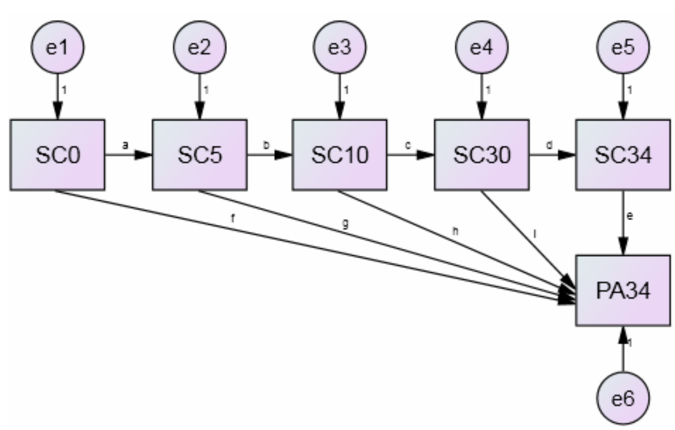

Fig. 1 Associations between social class across the life course and physical activity at age 34 years. This model reflects the accumulation of risk with additive effects hypothesis (all coefficients between social class across the life course and physical activity during adulthood are estimated). SC0-SC34 = social class at ages 0, 5, 10, 30, and 34 years. PA34 = physical activity at age 34 years

Model 2 – Accumulation of risk with trigger effect

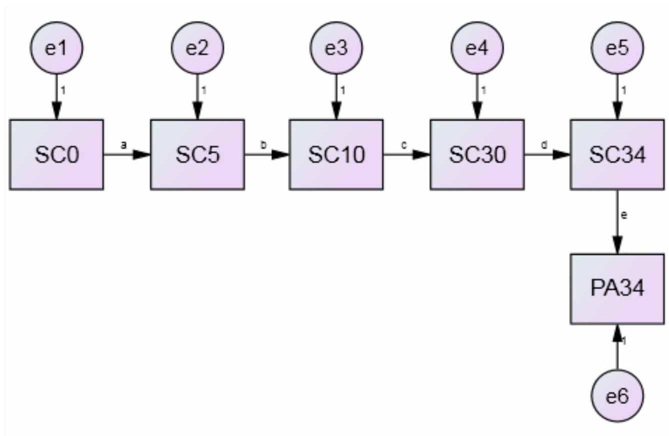

Fig. 2 Associations between social class across the life course and physical activity at age 34 years. This model reflects the accumulation of risk with trigger effect hypothesis (all coefficients between social class earlier in life and physical activity during adulthood are fixed to zero). SC0-SC34 = social class at ages 0, 5, 10, 30, and 34 years. PA34 = physical activity at age 34 years

Model 3 – Critical period

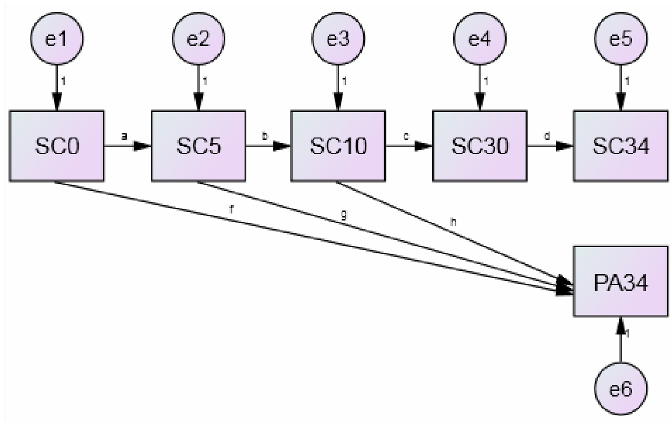

Fig. 3 Associations between social class across the life course and physical activity at age 34 years. This model reflects the critical period hypothesis (coefficients between social class during adulthood and physical activity during adulthood are fixed to zero). SC0-SC34 = social class at ages 0, 5, 10, 30, and 34 years. PA34 = physical activity at age 34 years

Because zero-inflated Poisson models were used, we used the Akaike information criterion (AIC) and the Bayesian information criterion (BIC) to compare the fit of the three competing models (lower AIC and BIC values indicate better fit) [26] [29]. Both AIC and BIC can be used to compare competing models, and these models do not need to be nested (in our comparison, models 2 and 3 were not nested) [26] [29]. For all models, maximum likelihood estimation with robust standard errors (MLR) was used to account for missing data.

RESULTS

Descriptive statistics are shown in Table 1. Bivariate correlations are shown in Table 2 (men) and Table 3 (women).

*** INSERT TABLE 1 HERE ***

*** INSERT TABLE 2 HERE ***

*** INSERT TABLE 3 HERE ***

For leisure-time physical activity, for men and women, model 1 fit the data best (Table 4). In this model, social class at all ages were significant predictors of social class later in life and of leisure-time physical activity at age 34 years (counts portion of the model). In addition, for men, social class at age 5 years was a significant predictor of leisure-time physical activity at age 34 years (logistic portion of the model), whereas for women, social class at all ages except at 5 years were significant predictors of leisure-time physical activity at age 34 years (logistic portion of the model).

*** INSERT TABLE 4 HERE ***

For physical activity at work, for men and women, model 1 fit the data best (Table 5). In this model, social class at all ages were significant predictors of social class later in life. In men, social class at age 34 years was a significant predictor of physical activity at work (logistic and counts portions of the model), whereas social class at ages 30 years and at birth were significant predictors of physical activity at work only for the logistic portion of the model. In women, social class at ages 30 and 34 years were significant predictors of physical activity at work for both the logistic and the counts portion of the model.

*** INSERT TABLE 5 HERE ***

For physical activity during transports, for men and women, model 1 fit the data best (Table 6). For men, social class was not a significant predictor of physical activity during transports. For women, social class at birth and at age 10 years were significant predictors of physical activity during transports.

*** INSERT TABLE 6 HERE ***

DISCUSSION

This study aimed to determine how social class across the life course is associated with physical activity during adulthood. Specifically, it aimed to integrate structural equation modeling with life course epidemiology theory to determine which life course model best explains the association between life course social class and physical activity during adulthood. Three life course models were compared: the accumulation of risk model with additive effects, the accumulation of risk model with trigger effect, and the critical period model. Three domains of physical activity were studied: physical activity during leisure time, physical activity during transports, and physical activity at work.

For all three domains of physical activity, the accumulation of risk model with additive effects fit the data best (model 1). In this model, social class at birth and at ages 5, 10, 30, and 34 years were associated with physical activity at age 34 years, although the magnitude and the direction of the associations for social class at each age varied by physical activity outcome and by sex.

In multivariate models, social class across the life course was associated with physical activity during transports for women, but not for men. Why would social class influence physical activity during transports for women and not for men? An explanation might be that, traditionally, men work outside the home, whereas women look after the children. Therefore, in lower social class households, if only one car is available, perhaps the man uses it, while the woman uses low-cost (and physically active) forms of transport, such as walking. On the contrary, in more affluent households, where two cars may be available, perhaps the woman also uses a car, and is thus less physically active during transports. More research is needed to test this hypothesis and to determine why low social class is associated with more transport-related physical activity for women and not for men.

For physical activity at work, model 1 fit the data best; however, model 2 had only slightly worse data fit (especially for BIC). As others have noted, disentangling life course hypotheses is challenging, and analysis of empirical data may not always provide a clear-cut answer [30]. Although we believe that structural equation modeling can be a helpful tool in selecting among competing models in life course epidemiology, this underlines the importance of considerations other than statistical in favouring a model, such as prior knowledge of specific causal mechanisms [30].

This study addressed a number of limitations commonly found in the literature on life course socioeconomic conditions and physical activity during adulthood. We used the same indicator of socioeconomic conditions (social class) throughout the life course because each indicator measures a different facet of socioeconomic conditions [31] (others have used different indicators at different points in time) [5, 6, 17, 19, 21]. We measured childhood socioeconomic conditions during childhood in a prospective cohort design to avoid recall and other bias [32] (others have measured them retrospectively in cross-sectional designs) [4, 6, 8, 9, 11, 12, 14, 18, 22, 24]. To pinpoint potential sensitive periods, we measured socioeconomic conditions at five points across the life course, starting at birth, twice during childhood, and twice during adulthood (others have generally measured them only once during childhood and once during adulthood) [1-4, 8-24]. We included socioeconomic conditions during adulthood in the statistical analysis as its association with physical activity is well established [33] (some have not) [2, 3, 7, 8, 13, 14, 17]. We included three outcomes for physical activity: physical activity during leisure time, at work, and during transports (others have studied leisure-time physical activity only) [1, 2-4, 6-9, 11-17, 19-24]. To the best of our knowledge, this study is the first to address all these limitations. Lastly, another strength of this study is its results were obtained on a large, nationally representative British cohort.

Nonetheless, some limitations must be noted in this study. Social class was based on the Register's General Classification of Occupation. This measure is widely used in epidemiological research, but its validity is sometimes contested. As well, a fair amount of data was missing on social class, especially at ages 5 years (20.3% missing) and 30 years (23.5% missing). This was more than in another British study [24], where 7-15% of data was missing for social class. All measures of physical activity were self-reported. As the 1970 British birth cohort was not designed for exhaustive measurement of physical activity, its survey questions on physical activity during leisure time, during transports, and at work were not validated. Therefore, our estimates could be biased due to measurement error, and our results should be interpreted with caution. In addition, as leisure-time physical activity tends to be overestimated in self-reports, objective measures such as doubly-labelled water, accelerometry, and VO_2 max tests would have provided better estimates [34]. These objective measures, however, are costly and time-consuming, and are seldom used in large samples (of the 24 studies we have reviewed, only one did not rely on self-reports) [16]. Physical activity during childhood was not measured. As physical activity is relatively stable through life [35] and social inequalities in physical activity have been found as early as adolescence [36], perhaps social class during childhood would have associated more strongly with physical activity during adulthood had this variable been measured. Physical activity at home was not measured, so we could not provide a full picture of the association between social class across the life course and physical activity during adulthood in all domains of life, and we could not fully adjust our analyses for physical activity in every other domain. Lastly, this was an observational study, from which causality cannot be inferred.

Conclusion

The accumulation of risk model with additive effects fit the data best for all three outcomes of physical activity we studied (physical activity during leisure time, at work, and during transports). In this model, and in our sample, social class at birth and at ages 0, 5, 10, 30, and 34 years were associated with physical activity during adulthood additively and independently of social class later in life, although the magnitude and direction of the associations varied by physical activity outcome and by sex. Structural equation modeling appears to be a helpful tool in selecting among competing models in life course epidemiology.

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	Men					Women				
	Age					Age				
	0	5	10	30	34	0	5	10	30	34
Social class										
I Professional	12.2	6.1	6.1	6.8	7.1	12.0	5.6	5.4	3.3	4.0
II Managerial-technical	30.7	19.3	25.6	29.4	35.8	31.3	19.0	25.8	25.5	30.4
IIINM Skilled non-manual	9.4	12.6	17.9	10.6	10.0	9.1	12.5	18.3	27.5	24.0
IIIM Skilled manual	31.3	30.4	25.6	26.0	27.9	31.4	30.5	25.0	5.3	4.6
IV-V Partly skilled-Unskilled	7.1	11.5	9.9	10.0	10.5	7.1	12.1	10.5	9.3	11.0
Missing	9.3	20.1	14.9	17.2	8.8	9.0	20.4	15.0	29.2	25.9
Physical activity	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
Exercises regularly										
Yes					78.0					79.5
No					21.6					20.2
Missing					.7					.3
Frequency of exercising										
Every day					14.5					20.0
4-5 days a week					10.6					11.2
2-3 days a week					26.8					25.6
Once a week					17.8					15.9
2-3 times a month					6.6					5.1
Less often					1.9					1.7
Does not exercise					21.6					20.2
Missing					.7					.3
Got out of breath or sweaty										
Most times					40.1					25.7
Sometimes					18.6					24.9
Rarely					10.1					13.6
Never					9.3					15.3
Does not exercise					21.6					20.2
Missing					.7					.3
Main form of transport										
Car/Motorcycle/Moped					82.9					79.4
Public transport					9.4					10.8

Cycling					2.8					1.1
Walking					3.6					7.8
Missing					1.3					1.0
Use a computer at work										
Yes					63.9					56.0
No					28.3					18.2
Missing					7.8					25.4
How often use computer at work										
Daily					57.2					47.3
2-4 times a week					3.6					5.6
Once a week					1.6					1.9
Less than once a week					1.4					1.3
Does not use computer at work					28.3					18.2
Missing					7.8					25.8

Highest parent's social class for ages 0, 5, and 10 years. The subject's own social class for ages 30 and 34 years. All figures are percentages (relative frequencies).

Table 1. Distribution (relative frequencies) of social class across the life course and physical activity at age 34 years for men (*n*=4,605) and women (*n*=5,019) in the 1970 British birth cohort

		Social class					Physical actvity		
		Birth	Age 5	Age 10	Age 30	Age 34	Leisure	Transport	Work
Social class	Birth	1							
	Age 5	.474**	1						
	Age 10	.485**	.661**	1					
	Age 30	.258**	.310**	.305**	1				
	Age 34	.249**	.296**	.307**	.673**	1			
PA	Leisure	-.080**	-.048**	-.086**	-.103**	-.107**	1		
	Transport	-.011	.004	-.002	-.055**	-.042*	.094**	1	
	Work	.215**	.235**	.262**	.518**	.609**	-.139**	-.056**	1

* Correlation is significant at the 0.01 level (2-tailed). ** Correlation is significant at the 0.001 level (2-tailed). PA = physical activity.

Table 2. Bivariate correlations among social class at birth and at ages 5, 10, 30, and 34 and physical activity at age 34 for men in the 1970 British birth cohort

		Social class					Physical actvity		
		Birth	Age 5	Age 10	Age 30	Age 34	Leisure	Transport	Work
Social class	Birth	1							
	Age 5	.455**	1						
	Age 10	.452**	.669**	1					
	Age 30	.221**	.264**	.283**	1				
	Age 34	.215**	.243**	.238**	.634**	1			
PA	Leisure	-.053**	-.077**	-.064**	-.055**	-.056**	1		
	Transport	.076**	.069**	.087**	0.032	.051*	.085**	1	
	Work	.136**	.155**	.153**	.358**	.438**	-0.009	.053**	1

* Correlation is significant at the 0.01 level (2-tailed). ** Correlation is significant at the 0.001 level (2-tailed). PA = physical activity.

Table 3. Bivariate correlations among social class at birth and at ages 5, 10, 30, and 34 and physical activity at age 34 for women in the 1970 British birth cohort

	Model 1 Accumulation of risk (additive effects)		Model 2 Accumulation of risk (trigger effect)		Model 3 Critical period	
	Men	Women	Men	Women	Men	Women
Fit indices						
AIC	226912	219823	259615	256310	241510	250676
BIC	227195	220110	259795	256582	241742	250911
Parameter estimates						
Social class on social class at the subsequent period						
SC34 SC30	0.281*	0.208*	0.535*	0.701*	0.671*	0.695*
SC30 SC10	0.141*	0.175*	0.325*	0.267*	0.262*	0.200*
SC10 SC5	0.389*	0.434*	0.655*	0.660*	0.391*	0.369*
SC5 SC0	0.428*	0.450*	0.477*	0.464*	0.413*	0.373*
Social class on leisure-time physical activity at age 34 (logistic portion of the model)						
PA SC34	0.072	0.171*	0.125*	0.058*		
PA SC30	0.018	-0.062*				
PA SC10	-0.012	0.106*			0.010	0.025
PA SC5	0.095*	-0.003			0.109*	0.030
PA SC0	0.054	0.088*			0.053	0.120*
Social class on leisure-time physical activity at age 34 (counts portion of the model)						
PA SC34	0.168*	0.218*	0.128*	-0.188*		
PA SC30	-0.207*	-0.284*				
PA SC10	-0.199*	0.186*			-0.197*	-0.101*
PA SC5	0.236*	-0.243*			0.237*	-0.155*
PA SC0	-0.049*	0.050*			-0.053*	0.110*

* = p < 0.05 (2-tailed). AIC = Akaike information criterion. BIC = Bayesian information criterion. PA = physical activity. SC = social class.

Table 4. Model fit and parameter estimates for structural equation models of social class at birth and at ages 5, 10, 30, and 34 years and leisure-time physical activity at age 34 years for men (n=4,605) and women (n=5,019) in the 1970 British birth cohort

	Model 1 Accumulation of risk (additive effects)		Model 2 Accumulation of risk (trigger effect)		Model 3 Critical period	
	Men	**Women**	**Men**	**Women**	**Men**	**Women**
Fit indices						
AIC	266650	278946	266803	279070	268244	279944
BIC	266933	279233	266983	279253	268476	280179
Parameter estimates						
Social class on social class at the subsequent period						
SC34 SC30	0.669*	0.689*	0.670*	0.692*	0.672*	0.695*
SC30 SC10	0.331*	0.275*	0.334*	0.279*	0.344*	0.283*
SC10 SC5	0.654*	0.656*	0.655*	0.660*	0.654*	0.657*
SC5 SC0	0.475*	0.459*	0.477*	0.464*	0.476*	0.457*
Social class on physical activity at work at age 34 (logistic portion of the model)						
PA SC34	-0.993*	-0.760*	-1.305*	-0.968*		
PA SC30	-0.457*	-0.349*				
PA SC10	-0.101	-0.001			-0.305*	-0.144*
PA SC5	-0.021	-0.015			-0.163*	-0.108*
PA SC0	-0.081*	-0.034			-0.160*	-0.097*
Social class on physical activity at work at age 34 (counts portion of the model)						
PA SC34	0.038*	0.028*	0.045*	0.047*		
PA SC30	0.009	0.030*				
PA SC10	0.006	0.009			0.011*	0.020*
PA SC5	0.008	0.003			0.010*	0.009
PA SC0	0.003	0.004			0.004	0.007

* = p < 0.05 (2-tailed). AIC = Akaike information criterion. BIC = Bayesian information criterion. PA = physical activity. SC = social class.

Table 5. Model fit and parameter estimates for structural equation models of social class at birth and at ages 5, 10, 30, and 34 years and physical activity at work at age 34 years for men (n=4,605) and women (n=5,019) in the 1970 British birth cohort

	Model 1 Accumulation of risk (additive effects)		Model 2 Accumulation of risk (trigger effect)		Model 3 Critical period	
	Men	Women	Men	Women	Men	Women
Fit indices						
AIC	292045	303563	293413	304312	293936	304707
BIC	292392	303915	293645	304546	294219	304994
Parameter estimates						
Social class on social class at the subsequent period						
SC34 SC30	0.481	0.559*	0.468*	0.545*	0.672*	0.695*
SC30 SC10	0.193	0.209*	0.331*	0.277*	0.346*	0.283*
SC10 SC5	0.629	0.649*	0.655*	0.660*	0.625*	0.648*
SC5 SC0	0.443	0.446*	0.477*	0.465*	0.443*	0.448*
Social class on physical activity during transports at age 34						
PA SC34	0.067	0.090	0.040	0.189*		
PA SC30	-0.072	0.054				
PA SC10	0.060	0.131*			0.058	0.148*
PA SC5	-0.010	0.022			-0.017	0.030
PA SC0	-0.018	0.072*			-0.018	0.080*

* = p < 0.05 (2-tailed). AIC = Akaike information criterion. BIC = Bayesian information criterion. PA = physical activity. SC = social class.

Table 6. Model fit and parameter estimates for structural equation models of social class at birth and at ages 5, 10, 30, and 34 years and physical activity during transports at age 34 years for men (n=4,605) and women (n=5,019) in the 1970 British birth cohort

Online Resource 1 - Physical activity scores

Physical activity score for leisure-time physical activity

Subjects were shown a list of common leisure-time physical activities (see card below). They were then asked: “Do you regularly take part in any of the activities on this card. By regularly I mean at least once a month, for most of the year?” Answers were: “yes” or “no”. Subjects who answered “yes” were then asked: “How often do you take part in any activity of this type?” Answers were: “every day”, “4-5 days a week”, “2-3 days a week”, “once a week", “2-3 times a month”, or “less often.” They were also asked: “And when you take part in any activity of this type, would you say you got out of breath or sweaty...” Answers were: “most times”, “sometimes”, “rarely,” or “never”. A physical activity score representing 8 weeks of habitual physical activity was computed based on these answers. Subjects who did not exercise were given a value of zero. The score for those who exercised was computed by multiplying how often they did so (frequency, over 8 weeks) by how often they got out of breath or sweaty (intensity). For frequency, subjects who exercised “every day” were given a value of 56 (8 weeks multiplied by 7 days a week). Those who exercised “4-5 days a week” were given a value of 36 (8 weeks multiplied by 4.5 days a week). Those who exercised 2-3 days a week were given a value of 20 (8 weeks multiplied by 2.5 days a week). Those who exercised once a week were given a value of 8 (8 weeks multiplied by 1 day a week). Those who exercised 2-3 times a month were given a value of 5 (2.5 days a month multiplied by 2 months [8 weeks was considered two months; this was necessary to obtain only integer values and treat this outcome as a count variable in the models]). Finally, those who exercised “less often” were considered to be exercising once every 4 weeks and were given a value of 2 (8 weeks multiplied by 1 day every 4 weeks). Next, for intensity, all subjects who got out of breath or sweaty “most times” were given a value of 4. Those who got out of breath or sweaty “sometimes” were given a value of 3. Those who got out of breath or sweaty “rarely” were given a value of 2. Finally, those who got out of breath or sweaty “never” were given a value of 1. These two sets of values were multiplied to compute the subjects’ physical activity score. The score took 23 values between 0 (no exercise at all) and 224 (subject exercises "every day" and gets out of breath or sweaty "most times"). This score approximated energy expenditure: the higher the score, the more physically active the subjects were and the more energy they expended through physical activities. The score was not normally distributed, having a range from 0 to 224 with a median of 40 and mode of 0. The score was positively skewed (skewness = 1.103; SE = 0.025; Kolmogorov-Smirnov test of normality with Lilliefors Significance Correction $p < 0.001$). The physical activity score was used at the dependent variable for leisure-time physical activity, and zero-inflated Poisson models were used to account for the large number of zeros and positive skewness.

Exercise

CARD NN

1. Take part in competitive sport of any kind
2. Go to 'keep fit' or aerobics classes
3. Go running or jogging
4. Go swimming
5. Go cycling
6. Go for walks
7. Take part in water sports
8. Take part in outdoor sports
9. Go dancing
10. Take part in any other sport or leisure activity which involves physical exercise

Source:

National Centre for Social Research (2004). 1970 British Cohort Study – 2004 Survey Appendix A, Fieldwork Documents, p. 136. Available at: http://www.cls.ioe.ac.uk/core/documents/download.asp?id=877&log_stat=1.

Physical activity score for physical activity at work

Subjects were asked: "Do you use a computer at work?" Answers were: "yes" or "no". Subjects who answered "Yes" were then asked: "How often do you use the computer?" Answers were: "Daily", "2-4 times a week", "Once a week", or "Less than once a week". A score for physical activity at work over 8 weeks was computed based on these answers. Subjects who said they did not use a computer at work were given a value of zero. Subjects who said they used a computer at work were given a value based on how often they said they used it in a week. Subjects who used a computer daily were given a value of 56 (8 weeks multiplied by 7 days a week). Subjects who used a computer 2-4 times a week were given a value of 24 (8 weeks multiplied by 3 days a week, the average of 2 and 4). Subjects who used a computer once a week were given a value of 8 (8 weeks multiplied by 1 day a week). Subjects who used a computer "less than once a week" were considered to be using a computer once every 4 weeks. They were given a value of 2 (8 weeks multiplied by 1 day every 4 weeks). The score for physical activity at work took 5 values between 0 and 56. The higher the score, the more subjects were using a computer at work, indicating less physical activity at work. To facilitate analysis and interpretation, the score was reverse coded, so that the higher the score, the less subjects were using a computer a work, indicating more physical activity at work (higher score, more physical activity at work). The (reverse coded) score could be interpreted as "how many days the participant does not use a computer at work over 8 weeks". The (reverse coded) score was not normally distributed, having a range from 0 to 56 with a median and a mode of 0. The (reverse coded) score was positively skewed (skewness = 0.634; SE = 0.027; Kolmogorov-Smirnov test of normality with Lilliefors

Significance Correction $p < 0.001$). This score was used at the dependent variable for physical activity at work, and zero-inflated Poisson models were used to account for the large number of zeros and positive skewness.

5.3.2 — Structural equation modeling for life course epidemiology: benefits and example

This paper is the second original contribution of this thesis. It reports on the Canadian dataset, and it is in preparation. Authors' contributions are as follows: Carl-Etienne Juneau, Sylvana Côté, and Louise Potvin contributed to study design, planning, and interpretation of the data. Carl-Etienne Juneau analyzed the data and wrote the manuscript. All authors commented on earlier drafts.

STRUCTURAL EQUATION MODELING FOR LIFE COURSE EPIDEMIOLOGY: BENEFITS AND EXAMPLE

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CEJ, SC, and LP contributed to study design, planning, and interpretation of the data. CEJ analyzed the data and wrote the manuscript. All authors commented on earlier drafts.

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Conflict of interest

We declare no conflict of interest.

STRUCTURAL EQUATION MODELING FOR LIFE COURSE EPIDEMIOLOGY: BENEFITS AND EXAMPLE

ABSTRACT

Background: A major challenge in life course epidemiology is to disentangle competing life course models. We aimed to show how structural equation modeling can be used to formally test competing models. We also aimed to highlight the benefits of this statistical technique over other techniques traditionally used in life course epidemiology to analyze life course data.

Methods: We used data on education, income, and physical activity from a large, nationally representative, prospective cohort of 16,903 Canadian children. We tested three competing life course models: the accumulation of risk model with cumulative effects, the accumulation of risk model with trigger effect, and the critical period model. We used structural equation modeling to test which model fit the data best and to determine how education and income at ages 8-9, 14-15, and 22-23 years were associated with leisure-time physical activity at age 22-23 years.

Results: For men, the critical period model fit the data best for education and income. For women, the accumulation of risk model with additive effects fit the data best for income, whereas education did not fit any model.

Conclusions: Structural equation modeling has three key strengths for life course epidemiology: (1) all associations between any number of variables can be estimated at once, (2) indirect associations can be estimated, and (3) competing models can be compared based on their fit to the data. Our results suggest that the patterns of associations between education and income across the life course and leisure-time physical activity during adulthood are gender- and indicator-specific.

MESH HEADING KEYWORDS

Health, Public Health, Epidemiology, Exercise, Longitudinal Studies, Social Class

Life course epidemiology aims to identify “long-term effects on chronic disease risk” of exposures early in life, and critical periods when exposure increases later risk markedly [1]. To understand these long-term effects on chronic disease risk, three major models have been proposed: the accumulation of risk model with cumulative effects, the accumulation of risk model with trigger effect, and the critical period model [1]. Briefly, in the accumulation of risk model with additive effects, each exposure increases risk of exposure in the subsequent period and has an independent effect on the outcome [1]. In the accumulation of risk model with trigger effect, each exposure increases risk of exposure during the subsequent period, but only the last exposure triggers the outcome [1]. Lastly, in the critical period model, exposure occurring during a period where susceptibility is greater has long-lasting and unalterable effects on the outcome [1].

A major challenge in life course epidemiology is to disentangle these competing life course models [1,2]. The statistical methods traditionally used in epidemiology are ill suited for this task and do not preserve the full conceptual richness of life course epidemiology theory [1-6]. Indeed, traditional regression-based techniques such as multiple or logistic regression do not allow for formal testing of competing life course models. This has lead some authors to propose the use of statistical methods that do allow competing models to be tested statistically, such structural equation modeling [4-6].

In this paper, we aimed to show how structural equation modeling can be used to formally test competing models in life course epidemiology. To this end, we applied structural equation modeling to life course data on socioeconomic position and physical activity, a key determinant of cardiovascular health. In doing so, we highlighted the benefits of using structural equation modeling over the regression-based statistical techniques traditionally used to analyze life course data. Specifically, we aimed to determine which life course model best represents the association between education and income across the life course and leisure-time physical activity during adulthood.

MATERIALS AND METHODS

Study design, setting, and participants

We used 1994, 2000, and 2008 data from a subsample of the National Longitudinal Survey of Children and Youth [7]. This Canadian, nationally representative, prospective cohort comprised 16,903 children aged 0-11 years in 1994. Sampling covered 99.5% of all Canadian children (children living in institutions or on Indian Reserves were excluded). In 2008, only children aged 22-23 years were asked about their leisure-time physical activity, our main outcome. Thus, our subsample comprised all subjects aged 22-23 years in 2008 (n=1,243). These subjects were aged 8-9 years in 1994 and 14-15 years in 2000. The study received ethics approval from the University of Montreal's Ethics Committee for Research in Health.

Variables and measurement

Predictor variables were education and income. Both were reported by parents when subjects were aged 8-9 years (in 1994) and 14-15 years (in 2000). Both were also self-reported by subjects at age 22-23 years (in 2008). The highest of the two parents' education was used as proxy for subjects' education at ages 8-9 years and 14-15 years. The subject's own self-reported educational attainment was used at age 22-23 years. Self-reports were recoded into years of education: education was a continuous variable. Household reported income was used as proxy for subjects at ages 8-9 years and 14-15 years. Personal income was used at age 22-23 years. Income was an ordinal variable with nine categories. The dependent variable was leisure-time physical activity. It was self-reported by subjects at age 22-23 years. Subjects were asked: “In the past 12 months, how often have you taken part in sports or done physical activities such as, swimming, aerobics, or some other sport?” Answers were: “never”, “less than once a week”, “1 to 3 times a week”, and “4 or more times a week.” Subjects were then asked: “Thinking of the sport or physical activity you do most often, how long do you usually spend being active in one session?” Answers were: “1 to 15 minutes”, “16 to 30 minutes”, “31 to 59 minutes”, “1 to 2 hours”, and “more than 2 hours”. A new variable was computed based on these two questions. It was equal to activity frequency per week (question 1) multiplied by usual session duration in minutes (question 2). This variable provided an estimate of how many minutes per week subjects spent in leisure-time physical activities over the past 12 months. Leisure-time physical activity was a continuous variable.

Statistical methods

Structural equation modeling in life course epidemiology. Gamborg et al. (2009) were among the first to apply structural equation modeling in epidemiology to life course data [5]. They proposed the term "life course path analysis" [5]. Simply, life course path analysis is path analysis technique applied to life course data. Path analysis is an extension of regression analysis [8]. In structural equation modeling, it is referred to as the structural model [9]. In path analysis, regressions coefficients among any number of variables are estimated simultaneously, taking into account the entire correlation matrix among all variables in the model. In a life course path analysis, the same independent variable measured multiple times across the life course acts as its own predictor and outcome: measures at each point in time are predicted by the previous measure and predict the next (Figure 1). We will refer to this as the independent variable path. Then, any number of measures along the independent variable path can act as predictors for the final outcome of interest. In an accumulation of risk model with additive effects, all measures along the independent variable path are theorized to act as predictors (Figure 1, A). In an accumulation of risk model with trigger effect, only the last measure along the independent variable path is theorized to act as a predictor (Figure 1, B). Lastly, in a critical period model, only measures early in life are theorized to act as predictors (Figure 1, C). Life course path analysis has three major benefits over traditional regression-based techniques. First, it is more parsimonious and it has more statistical power for estimating complex associations among multiple variables. Indeed, all associations between any number of variables in the model can be estimated at once. In traditional regression-based techniques (such as multiple regression), only the associations between each predictor variable and the outcome are estimated. Associations between predictors are not estimated, and additional regressions need to be performed to obtain these estimates. This approach is not parsimonious, and it can lead to inflated type 1 error. Second, indirect associations can be estimated. That is, using structural equation modeling, we can estimate how strongly socioeconomic position during childhood is associated with physical activity during adulthood directly (independently) and also indirectly through socioeconomic position during adulthood. The standard approach to estimating indirect associations in traditional regression-based techniques is to estimate each indirect association separately in a series of regression analyses (Baron and Kenny, 1986). This approach is not parsimonious. Also, it has low statistical power (MacKinnon et al., 2002). Third, competing models can be compared based on goodness of fit statistics. For each model, structural equation modeling provides fit indices. These indices can be compared across models to determine which model fits the data best. Many fit indices have been developed for structural equation modeling, and their interpretation is well documented (Boomsma, 2000; McDonald and Ringo Ho, 2002; Tabachnick and Fidell, 2007). In addition, for nested models, a formal statistical test of significance exists to determine which model fits the data best. In contrast, estimates of different models obtained using traditional regression-based techniques cannot be formally compared using a statistical test.

Statistical analysis. Prior to analysis, all variables were examined for accuracy of data entry, missing values, and fit between their distributions and the assumptions of multivariate analysis. Weekly minutes of physical activity was skewed to the right. To improve its distribution, its square root was used. Descriptive statistics were obtained using standard methods in SPSS 18 and (SPSS Inc, IL, USA). Life course path models were represented graphically using AMOS 20 (SPSS Inc, IL, USA). Analysis was carried out using MPLUS 6.11 (Muthen & Muthen, CA, USA). Three models were compared: the accumulation of risk model with additive effects (Figure 1, A), the accumulation of risk model with trigger effect (Figure 1, B), and the critical period model (Figure 1, C). For both accumulation of risk models, the indirect association of education at age 8-9 years with physical activity at age 22-23 years through education at age 22-23 years was also estimated. For the critical period model, residuals of final outcomes were covaried to take into account any missing covariates. Models were estimated separately for each gender and for education and income. For each model, the following statistics were reported: χ^2 goodness-of-fit and its degrees of freedom and *P* value, root mean squared error of approximation (RMSEA) and its 90% confidence interval, comparative fit index (CFI), Tucker Lewis index (TLI), and standardized estimates of path coefficients. Education, income, and leisure-time physical activity were treated as continuous variables in the models and maximum likelihood estimation was used.

RESULTS

Descriptive statistics

Education, income, and physical activity variables are shown for men and women in Table 1. On average, men spent 156.26 (± 145.10) minutes per week in leisure-time physical activities, whereas woman spent 110.90 (± 120.90) minutes. Low correlations were found for men (Table 2) and women (Table 3) between education at age 22-23 years and physical activity at age 22-23 years (r=0.172 for men; r=0.152 for women, both p<0.01), between income at age 8-9 years and physical activity at age 22-23 years (r=0.135 for men; r= 0.141

for women, both $p<0.01$), and between income at age 14-15 years and physical activity at age 22-23 years ($r=0.085$, $p<0.05$ for men; $r=0.141$, $p<0.01$ for women). In addition, a low correlation was found between income at age 22-23 years and physical activity at age 22-23 years for women ($r=0.092$, $p<0.05$), but not for men.

Life course path analysis for men

For education, the critical period model fit the data best (Table 4). In this model, the only predictor of physical activity at age 22-23 years was the highest parent's education at age 8-9 years. Their estimated direct association was 0.113 ($P < 0.01$). For income, the critical period model also fit the data best (Table 4). In this model, the only predictor of physical activity at age 22-23 years was household income at age 8-9 years. Their estimated direct association was 0.134 ($P < 0.001$).

Life course path analysis for women

For education, none of the tested models fit the data well (Table 5). For income, the accumulation of risk model with additive effects fit the data best (Table 5). In this model, personal income at age 22-23 years and household income at age 8-9 years were predictors of physical activity at age 22-23 years. The estimated direct association between personal income at age 22-23 years and physical activity at age 22-23 years was 0.090 ($P < 0.05$). The estimated total association between household income at age 8-9 years and physical activity at age 22-23 years was 0.140 ($P < 0.001$). Of this association, 0.097 was direct ($P < 0.05$) and 0.043 was indirect ($P = 0.127$; not significant).

DISCUSSION

This study aimed to show how structural equation modeling can be used to formally test competing models in life course epidemiology. To this end, we determined which life course model best represents the association between education and income across the life course and leisure-time physical activity during adulthood. Three life course epidemiology models were tested and compared based on goodness-of-fit statistics: the accumulation of risk model with cumulative effects, the accumulation of risk model with trigger effect, and the critical period model. For men, the critical period model fit the data best for education and income. In this model, for education, the only predictor of physical activity at age 22-23 years was the highest parent's education at age 8-9 years. For income, the only predictor of physical activity at age 22-23 years was household income at age 8-9 years. For women, none of the tested models fit the data well for education, whereas the accumulation of risk model with cumulative effect fit the data best for income. In this model, personal income at age 22-23 years and household income at age 8-9 years were both predictors of physical activity at age 22-23 years.

For men, these results suggest that: (1) low parental education and low household income during childhood may lower physical activity during adulthood; (2) childhood may be a sensitive period for physical activity during adulthood; and (3) education and income show a similar pattern of association. For women, these results suggest that: (1) low income during childhood and low income during adulthood may lower physical activity during adulthood; (2) these associations appear to be independent of each other; (3) income may be a better life course predictor of physical activity than education; and (4) income during childhood and during adulthood may play a more important role than income during adolescence. Furthermore, collectively, these results suggest that socioeconomic position during adolescence do not seem to be associated with physical activity during adulthood (neither education nor income was a predictor in any of the models for both genders).

Others studies [10-16], but not all [17, 18], have found similar associations. Of the nine studies we have reviewed, seven found an association between education [10-14] or income [15-16] during childhood and physical activity during adulthood. The other two [18, 19] failed to find an association among these variables. Seven of these nine studies used regression-based techniques, including logistic regression [13, 18], multiple linear regression [10, 11, 17], Poisson's regression [15], and log multinomial regression [14]. The other two studies used ANOVA [12] and χ^2 test [16]. Because they used regression-based techniques (or simpler methods), none of these studies could estimate the indirect association between education during childhood and physical activity during adulthood. It is likely these two variables are associated indirectly, through education during adulthood, because (1) education during childhood is associated with education during adulthood [19] and (2) education during adulthood is associated with physical activity during adulthood [20]. Therefore, in any life course analysis of education and physical activity, at least three variables must be included in the model: education during childhood, education during adulthood, and physical activity during adulthood. If education during childhood is missing, we are likely to overestimate the association between education during adulthood and physical activity during adulthood. If education during adulthood is missing, we are likely to overestimate the association between education during childhood and physical activity during adulthood. Lastly, if the model does not estimate the indirect association between education during childhood and physical activity during adulthood through education during adulthood, we are likely to overestimate the association of either one of these independent variables, depending on model specification (e.g. in stepwise regression, the first education variable we enter in the model is attributed all indirect association, and this would overestimated its true association). The same reasoning holds true for income in this dataset, or, more generally, for any other variable along the independent variable path when analyzing data in life course epidemiology. Therefore, we argue that using life course path analysis to model indirect associations provides more valid estimates.

This study improved in other ways on the methodology used previously in research on life course socioeconomic position and physical activity. Two indicators of socioeconomic position were used (education and income) to examine differences in their pattern of association (four of the nine studies we have reviewed used only one) [12, 14, 15, 18]. In each model, the same indicator of socioeconomic position (education or income) was used throughout the life course, as each indicator captures a different aspect of socioeconomic position [21] (others have used different indicators at different points in time) [16]. Childhood socioeconomic position was measured during childhood in a prospective cohort design to avoid recall and other bias [22] (others have measured them retrospectively in cross-sectional designs) [14, 16, 17]. Socioeconomic position was measured at three points in time: once during childhood, once during adolescence and once during adulthood to pinpoint sensitive periods (others have measured socioeconomic position at only two points in time: once during childhood and once during adulthood) [10-15, 17, 18]. Socioeconomic position during adulthood was included in the statistical analysis (some studies did not include socioeconomic position during adulthood in their statistical analysis, even though its association with physical activity is well established [20]) [10-13, 15, 16]. Another strength of this study is its results were obtained on a large, nationally representative (Canadian) cohort.

Still, this study had a number of limitations. Data was missing for education at age 14-15 years (13.20% missing for men; 14.70% missing for women) and for income at ages 8-9 years (11.09% for men; 15.37% for women) and 14-15 years (20.10% for men; 19.05% for women). All measures were self-reported, including physical activity, which is often overreported [23]. Models 2 (trigger effect) and 3 (critical period) did not have the same number of degrees of freedom, as residuals of final outcomes were covaried in model 3. This is standard practice, but it affects model fit, and it might explain why model 3 fit the data better. Objective measures of physical activity would have reduced measurement error [23]. However, these measures are expensive, time-consuming, and rarely used in large cohorts. Of the nine studies we have reviewed, eight relied entirely on self-reports [11-14, 16-19]. Data collection for this cohort began when subjects were aged 8-9 years: perhaps sensitive periods earlier in life were missed. Subjects were aged 22-23 years at the last follow-up: the patterns of associations we found may change later in adulthood. Lastly, this was an observational study, from which causality cannot be inferred.

To conclude, education and income during childhood, adolescence, and adulthood show different patterns of association with physical activity during adulthood for men and women. For men, this pattern for education and income fit the critical period model best. Thus, for men, low parental education and low household income during childhood were associated with low physical activity during adulthood. For woman, education did not fit any model, whereas income fit the accumulation of risk model with additive effects. Thus, for women, low income during childhood and low income during adulthood were associated with low physical activity during adulthood independently of each other. This suggests that the association of life course socioeconomic position and physical activity during adulthood may be gender- and indicator-specific. For life course epidemiology, these results show how structural equation modeling can be used to compare competing models. They also illustrate the benefits of using structural equation modeling over other statistical techniques traditionally used in life course epidemiology to analyze life course data.

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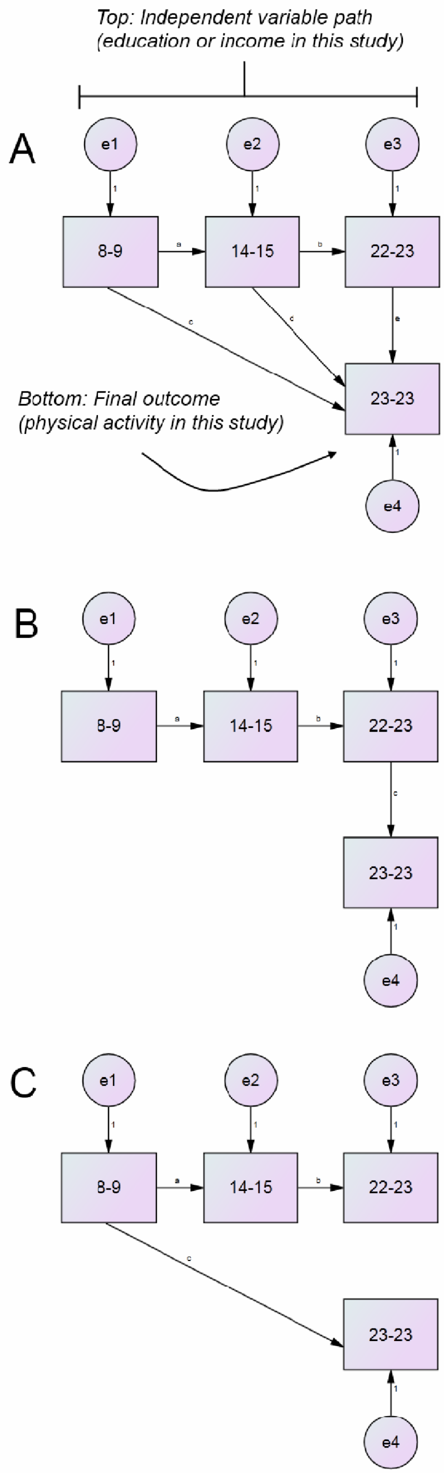
Top: Independent variable path
(education or income in this study)
A
e1
e2
e3
8-9
14-15
22-23
23-23
e4
Bottom: Final outcome
(physical activity in this study)
B
e1
e2
e3
8-9
14-15
22-23
23-23
e4
C
e1
e2
e3
8-9
14-15
22-23
23-23
e4

Fig. 1 Life course path analysis of socioeconomic position (education or income) at ages 8-9, 14-15, and 22-23 years and physical activity at age 22-23 years. Top (A): Accumulation of risk model with additive effects (all measures along the independent variable path are predictors). Middle (B): Accumulation of risk model with trigger effect (only the last measure along the independent variable path is a predictor). Bottom (C): Critical period model (only the measure early in life is a predictor).

	Men			Women		
	Age			Age		
	8-9 (1994)	14-15 (2000)	22-23 (2008)	8-9 (1994)	14-15 (2000)	22-23 (2008)
<u>Socioeconomic conditions</u>						
Years of education						
Mean (SD)	12.67 (2.67)	13.01 (2.73)	13.57 (3.19)	12.56 (2.75)	12.84 (2.61)	14.47 (2.97)
Missing (%)	2,30	13,20	,00	2,60	14,70	,00
Household income (Canadian $)						
$80,000 or more	15,36	24,06	10,53	15,29	27,23	2,65
$60,000 - $79,999	19,85	21,34	6,24	20,31	16,21	3,56
$50,000 - $59,999	16,28	9,83	12,05	11,17	8,66	5,17
$40,000 - $49,999	16,55	9,05	15,50	13,88	8,85	10,76
$30,000 - $39,999	12,02	6,78	13,87	12,65	9,25	14,50
$20,000 - $29,999	6,01	6,03	10,55	6,83	6,85	20,68
$15,000 - $19,999	1,19	1,58	16,17	2,55	1,72	19,45
$10,000 - $14,999	1,66	1,24	9,07	1,96	2,18	15,03
$9,999 or less	,00	,00	6,01	,00	,00	8,20
Missing (%)	11,09	20,10	,00	15,37	19,05	,00
<u>Physical activity</u>						
Frequency of physical activity						
4 or more times a week			18,04			14,87
1 to 3 times a week			47,77			42,66
Less than once a week			20,08			23,47
Never			14,11			19,00
Missing			,00			,00
Usual duration of session						
More than 2 hours			14,97			7,15
1 to 2 hours			45,59			33,56
31 to 59 minutes			17,21			24,94
16 to 30 minutes			7,78			12,71
1 to 15 minutes			,34			2,64
Does not exercise			14,10			19,00
Missing			,00			,00
Weekly minutes of physical activity						
Mean (SD)			156.26 (145.10)			110.90 (120.90)
Missing			,00			,00

SD = standard deviation. The highest parent's years of education was used for ages 8-9 years and 14-15 years. The subject's own years of education was used for age 22-23 years. Household income was used for ages 8-9 and 14-15 years. Personal income was used for ages 22-23 years. Personal income categories for age 22-23 years (not shown) were: $4,999 or less, $5,000 - $9,999, $10,000 - $14,999, $15,000 - $19,999, $20,000 - $24,999, $25,000 - $29,999, $30,000 - $39,999, $40,000 - $49,999, $50,000 or more. Figures are percentages unless otherwise noted.

Table 1. Distribution of Education and Income Across the Life Course and Physical Activity at Age 22-23 Years for Men (*n* =669) and Women (*n=711*) in the National Longitudinal Survey of Children and Youth, Canada, 1994-2008

		Education			Income			PA
		8-9	14-15	22-23	8-9	14-15	22-23	Leisure
EDU	8-9	1						
	14-15	0.011	1					
	22-23	0.048	-0.069	1				
INC	8-9	0.080*	-0.025	0.209**	1			
	14-15	0.177**	-0.035	0.211**	0.618**	1		
	22-23	-0.038	-0.016	-,209**	-,107**	-0.065	1	
PA	Leisure	0.049	0.040	0.172**	0.135**	0.085*	-0.020	1

EDU = education. INC = income. PA = physical activity. * Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed).

Table 2. Bivariate Correlations Among Education, Income, and Physical Activity for Men in the National Longitudinal Survey of Children and Youth, Canada, 1994-2008

		Education			Income			PA
		8-9	14-15	22-23	8-9	14-15	22-23	Leisure
EDU	8-9	1						
	14-15	0.018	1					
	22-23	0.039	-0.028	1				
INC	8-9	0.067	-0.063	0.236**	1			
	14-15	0.172**	-0.006	0.207**	0.558**	1		
	22-23	0.018	-0.033	-,074*	-0.008	-0.023	1	
PA	Leisure	-0.048	-0.017	0.152**	0.141**	0.141**	0.092*	1

EDU = education. INC = income. PA = physical activity. * Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed).

Table 3. Bivariate Correlations Among Education, Income, and Physical Activity for Women in the National Longitudinal Survey of Children and Youth, Canada, 1994-2008

	Education			Income		
	Model 1 Accumulation of risk (additive effects)	Model 2 Accumulation of risk (trigger effect)	Model 3 Critical period	Model 1 Accumulation of risk (additive effects)	Model 2 Accumulation of risk (trigger effect)	Model 3 Critical period
Fit indices						
x2	4.864	8.359	4.921	3.126	14.334	3.176
df	1	3	2	1	3	2
p	0.0274	0.039	0.085	0.077	0.003	0.204
RMSEA	0.075	0.051	0.046	0.058	0.077	0.030
(90% CI)	(0.020 - 0.147)	(0.010 - 0.094)	(0.000 - 0.099)	(0.000 - 0.136)	(0.040 - 0.119)	(0.000 - 0.090)
CFI	0.996	0.995	0.997	0.992	0.958	0.996
TLI	0.979	0.990	0.992	0.953	0.916	0.987
Parameter estimates						
Education/income on education/income at the subsequent period						
22-23 on 14-15	0.266**	0.266**	0.266**	-0.087*	-0.087*	-0.086*
14-15 on 8-9	0.902**	0.902**	0.902**	0.625**	0.625**	0.625**
Education/income on physical activity at age 22-23						
PA22-23 on 22-23	0.171**	0.190**		-0.021	-0.036	
PA22-23 on 14-15	-0.023			0.011		
PA22-23 on 8-9 (direct)	0.093	0.093	0.113*	0.126*		0.134**
PA22-23 on 8-9 (indirect)	0.020	0.046**		0.008	0.002	
PA22-23 on 8-9 (total)	0.113*	0.046**		0.134*	0.002	

RMSEA = root mean square error of approximation. CFI = comparative fit index. TLI = Tucker Lewis index. PA = physical activity. PA = physical activity. * = $p < 0.05$. ** = $p < 0.001$.

Table 4. Model Fit and Parameter Estimates for Structural Equation Models of Education and Income at Ages 8-9, 14-15, and 22-23 years and Leisure-time Physical Activity at Age 22-23 Years for Men in the National Longitudinal Survey of Children and Youth, Canada, 1994-2008

	Education			*Income*		
	Model 1 Accumulation of risk (additive effects)	Model 2 Accumulation of risk (trigger effect)	Model 3 Critical period	Model 1 Accumulation of risk (additive effects)	Model 2 Accumulation of risk (trigger effect)	Model 3 Critical period
Fit indices						
x2	15.683	25.088	18.724	0.211	16.477	2.539
df	1	3	2	1	3	2
p	0.000	0.000	0.000	0.646	0.001	0.281
RMSEA	0.141	0.100	0.106	0.000	0.082	0.020
(90% CI)	(0.085 - 0.206)	(0.066 - 0.137)	(0.066 - 0.153)	(0.000 - 0.079)	(0.046 - 0.123)	(0.000 - 0.082)
CFI	0.988	0.981	0.986	1.000	0.940	0.998
TLI	0.925	0.963	0.957	1.021	0.879	0.993
Parameter estimates						
Education/income on education/income at the subsequent period						
22-23 on 14-15	0.300**	0.300**	0.298**	-0.038	-0.0380	-0.042
14-15 on 8-9	0.898**	0.898**	0.898**	0.564**	0.564**	0.564**
Education/income on physical activity at age 22-23						
PA22-23 on 22-23	0.117*	0.153**		0.090*	0.087*	
PA22-23 on 14-15	0.116			0.080		
PA22-23 on 8-9 (direct)	0.002		0.138**	0.097*		0.140**
PA22-23 on 8-9 (indirect)	0.136	0.096**		0.043	-0.002	
PA22-23 on 8-9 (total)	0.138**	0.096**		0.140**	-0.002	

RMSEA = root mean square error of approximation. CFI = comparative fit index. TLI = Tucker Lewis index. PA = physical activity. PA = physical activity. * = p < 0.01. ** = p < 0.001.

Table 5. Model Fit and Parameter Estimates for Structural Equation Models of Education and Income at Ages 8-9, 14-15, and 22-23 Years and Leisure-Time Physical Activity at Age 22-23 Years for Women in the National Longitudinal Survey of Children and Youth, Canada, 1994-2008

SECTION 6 — DISCUSSION

6.1 — Key results

The overarching goal of this thesis was to determine if there is a life course association between socioeconomic position early in life and physical activity during adulthood. If there was one, a second goal was to determine which theoretical model in life course epidemiology best described its pattern.

Our first goal was to determine if the literature supported the hypothesis that there is a life course association between socioeconomic position early in life and physical activity during adulthood. This goal was achieved by carrying out a systematic review (Juneau et al., 2015). We hypothesized that the bulk of the evidence would support the notion that there is indeed a long-lasting, life course association between socioeconomic position early in life and physical activity during adulthood. In our systematic review of 10,619 publications (of which 42 were included for analysis), for outcome "physical activity" (all types and measures), a significant association with socioeconomic position during childhood was found in 26/42 studies (61.9%). When the only outcome considered was leisure-time physical activity, a significant association was found in 21/31 studies (67.7%). In a subset of 21 studies that used more rigorous methodology, proportions of study finding an association was higher: 15/21 (71.4%) for all types and measures of physical activity and 12/15 (80%) for leisure-time physical activity only. We concluded that the bulk of the evidence supported the notion that there is a life course association between socioeconomic position early in life and physical activity during adulthood and that this hypothesis was supported more consistently for leisure-time physical activity and in studies using more rigorous methodology.

A secondary aim of this systematic review was to highlight the methodological limitations most commonly found in this body of literature to make recommendations to strengthen future research. We have highlighted nine important limitations found repeatedly in the literature on socioeconomic position during childhood and physical activity during adulthood. These common limitations were: (1) different indicators of socioeconomic position were used at different points in time over the life course; (2) socioeconomic position during childhood was assessed retrospectively, during adulthood; (3) socioeconomic position during adulthood was not controlled for, or included in the statistical analysis; (4) cross-sectional designs were used; (5) variables were measured for only two points in time over the life course; (6) authors did not specify for what age childhood socioeconomic conditions were measured (7) non valid measures of physical activity were used; (8) leisure-time physical activity was the only outcome; and (9) the statistical methods used did not translate into practice the full richness of life course epidemiology theory.

We have made the following recommendations to strengthen future research into this field: (1) use the same indicator of socioeconomic position throughout the life course; (2) measure childhood socioeconomic position during childhood (avoid retrospective measurement); (3) include socioeconomic position during adulthood in the statistical analysis; (4) use a prospective study design (for causal inference); (5) measure at multiple points in time across the life course (at least once during childhood, once during adolescence, and once during adulthood); (6) specify for what age socioeconomic position during childhood was measured; (7) use valid measures of physical activity (such as accelerometers or, at the very least, validated questionnaires); (8) measure physical activity in all domains of life (not just during leisure-time); (9) use structural equation modeling to analyze life course data.

This thesis' second goal was to determine which theoretical model in life course epidemiology best described the pattern of associations between socioeconomic position across the life course and physical activity during adulthood. This goal was accomplished by carrying out original research in two prospective cohorts. In this research, three theoretical models in life course epidemiology were examined: the accumulation of risk model with additive effects, the accumulation of risk model with trigger effect, and the critical period model. Following the accumulation of risk model with additive effects, we hypothesized that socioeconomic position during childhood, during adolescence, and during adulthood are associated with physical activity during adulthood directly, irrespective of later exposure (an independent association) and also indirectly through socioeconomic position later in life (mediation).

The results of our own original research are summarized in Table 1. We have found the following: (1) in Canadian men, for leisure-time physical activity, the critical period model fit the data best for education and income; (2) in Canadian women, for leisure-time physical activity, the accumulation of risk model with additive effects fit the data best for income; (3)

in Canadian women, for leisure-time physical activity, education did not fit any model; and (4) in British men and women, for physical activity during leisure time, at work, and during transports, the accumulation of risk model with additive effects fit the data best for social class. Our hypothesis was thus only partially confirmed, with support from British data for all outcomes of physical activity in relation to social class, and with support from Canadian data for leisure-time physical activity as the outcome in relation to income (but not education). This places the results of our systematic review somewhat at odds with the results of our own analyses of Canadian data, but in accord with our analysis of British data.

	Model 1 Accumulation of risk (additive effects)		Model 2 Accumulation of risk (trigger effect)		Model 3 Critical period	
	Men	Women	Men	Women	Men	Women
Canadian data						
Education						
Leisure time					X	
Income						
Leisure time		X			X	
British data						
Social class						
Leisure time	X	X				
Work	X	X				
Transports	X	X				

X = This model fit the data best for that physical activity outcome in that sample. Education did not fit any model for women in the Canadian dataset.

Table 1. Summary of results obtained in the Longitudinal National Survey of Children and Youth (Canadian data) and in the 1970 British birth cohort (British data) on the association between socioeconomic position across the life course and physical activity during adulthood according to three widely used conceptual models in life course epidemiology

Overall, we conclude that **the bulk of the evidence points to a pattern of associations best represented by the accumulation of risk model with additive effects.** That is, socioeconomic position at each point of the life course seems to be associated with physical activity during adulthood directly, irrespective of later exposure (an independent association) and also indirectly through socioeconomic position later in life (mediation). In our own analyses, this was especially true for British data on social class. Canadian data on income (for women only) also provided partial support. Lastly, the results of our systematic review also support the notion that this pattern of associations is best represented by the accumulation of risk model with additive effects. In Canadian data for men, however, the critical period model was supported for education and income, with physical activity during leisure time as the outcome. This may be due to differences in study population (Canadian vs. British), sex (male vs. female), measures of socioeconomic position (income vs. education vs. social class), or to interactions among these three factors. Moreover, in Canadian women, education did not fit any model, indicating that, perhaps, it follows a pattern of associations we have not studied. This suggests that while the bulk of the evidence points to the accumulation of risk model with additive effects, this model may not apply for all indicators of socioeconomic position, for all outcomes of physical activity, or in all populations.

In carrying out our own original research, we aimed to improve on the methodological limitations highlighted in our systematic review. We have done so by (1) using the same indicators of socioeconomic position throughout the life course (social class in the British data, education and income in the Canadian data); (2) measuring childhood socioeconomic position during childhood in prospective study designs to avoid recall and other bias; (3) measuring socioeconomic position at multiple points across the life course (five points in the British data, three points in the Canadian data); (4) including socioeconomic position during adulthood in the statistical analysis; (5) including multiple outcomes for physical activity: physical activity during leisure time, during transports, and at work (in the British data); and (6) using structural equation modeling to compare competing models in life course epidemiology. To the best of our knowledge, our original research papers were the first to address all these limitations. Finally, another strength of our research was that its results were obtained on large, nationally representative prospective cohorts.

A secondary objective for this thesis was to contribute to bridging the gap between theory and methods in life course epidemiology by showing how structural equation modeling can be used to estimate associations and model fit of life course data according to three widely used conceptual models in life course epidemiology: the accumulation of risk model with trigger effect, the accumulation of risk model with additive effects, and the critical period model. In doing so, we have shown that with structural equation modeling: (1) all associations between any number of variables in the model can be estimated at once; (2) indirect associations can be estimated; (3) competing models can be compared based on goodness of fit statistics. This illustrated the benefits of using structural equation modeling over other statistical techniques traditionally used in life course epidemiology to analyze life course data. We believe that structural equation modeling is a promising tool for life course epidemiology.

6.2 — Possible mechanisms and explanations

How can we explain the association between socioeconomic position across the life course and physical activity during adulthood? Before we try to answer this question, it should be noted that the answer to this question was beyond the scope of this thesis; we have not carried out analysis of mediating variables, and the explanation we put forth here is hypothetical. This explanation is based on the literature on fundamental movement skills and Stodden et al.'s (2008) developmental model of physical activity participation.

Indeed, fundamental movement skills and motor competence may explain the association of socioeconomic position during childhood and across the life course with physical activity during adulthood. According to Stodden et al.'s (2008) developmental model, physical activity provides opportunities to increase motor competence (actual and perceived) as well as health-related fitness. In turn, increased motor competence and health-related fitness drive increasing physical activity and a healthy body weight in a virtuous feedback loop involving more physical activity, more opportunities to increase motor competence and more health-related fitness.

Based on this theory, we could hypothesize that low socioeconomic position early in life limits the development of motor competency and launches the child on a life course of low physical activity. This seems plausible, as there is evidence that children from low socioeconomic background have delayed mastery of fundamental movement skills (Goodway et al., 2013).

Possible explanations for this delay include fewer opportunities for physical activity for children in low socioeconomic position households, more perceived barriers by parents (e.g. financial costs) (Smith et al., 2010), no physically active role model (as parents are more likely to be inactive) (Gidlow et al., 2006), and less value placed on physical activity by parents in such households (Stockie, 2009), potentially reducing the likelihood that they will raise their children to be physically active.

Limiting the development of motor competency during childhood would launch the child on a life course of low physical activity, increasing risk of unhealthy body weight, which would feedback continuously into diminishing levels of physical activity throughout the life course, leading to low levels of physical activity during adulthood. This hypothesis could be tested in future research by including measures of motor competency in structural equation models as mediating variables between socioeconomic position during childhood and physical activity during adulthood.

6.3 — A new theoretical model to describe the association between socioeconomic position during childhood and physical activity during adulthood from a life course perspective

Based on the research reviewed for this thesis, and our own findings, we can propose a theoretical model linking socioeconomic position and physical activity within a life course perspective (Figure 4). This model comprises childhood, adolescence, and adulthood.

The first component of the model is socioeconomic position. In this model, socioeconomic position tracks throughout the life course. That is, low socioeconomic position during childhood increases risk of low socioeconomic position during adolescence, which in turn increases risk of low socioeconomic position during adulthood.

The second component of this model is physical activity. In this model, physical activity tracks throughout the life course as well. Low physical activity during childhood increases risk of low physical activity during adolescence, which in turn increases risk of low physical activity adulthood.

The third component of this model is fundamental movement skills. Fundamental movement skills mediate (in part) the association between socioeconomic position during childhood and physical activity during adolescence and adulthood. There may be other mediators of this association, but they are beyond the scope of this model.

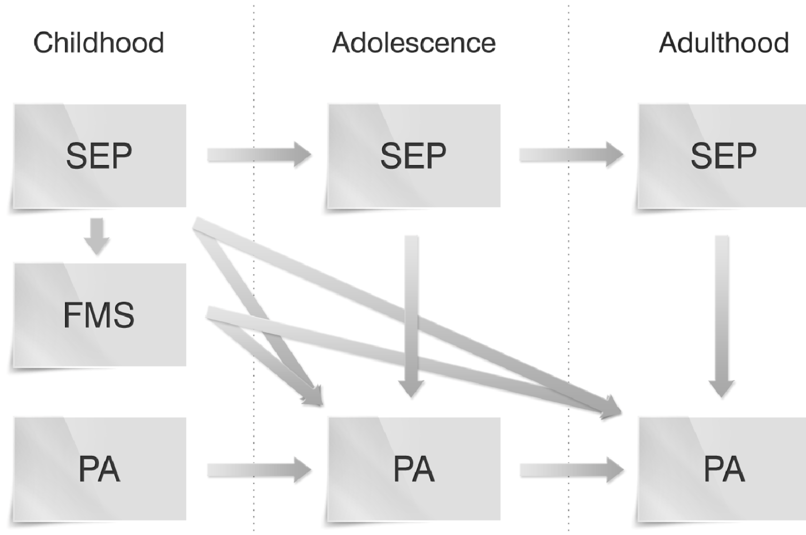

Figure 4. Theoretical model illustrating the associations between socioeconomic position and physical activity from a life course perspective. In this model, socioeconomic position (SEP) tracks throughout the life course (top path). Physical activity (PA) tracks throughout the life course as well (bottom path). Socioeconomic position is associated with fundamental movement skills during childhood (first column). Socioeconomic position is associated with physical activity cross-sectionally during adolescence (middle column) and during adulthood (third column). In addition, socioeconomic position during childhood is associated with physical activity during adolescence and during adulthood. These associations are mediated (in part) by mastery of fundamental movement skills (FMS) during childhood. SEP = socioeconomic position. FMS = fundamental movement skills. PA = physical activity.

Thus, high or low socioeconomic position during childhood may contribute to launching the child on two opposite life courses of physical activity. High socioeconomic position during childhood would increase the likelihood of mastering fundamental movement skills during childhood, leading to increased physical activity during adolescence and during adulthood. On the contrary, low socioeconomic position during childhood would result in poor mastery of fundamental movement skills during childhood, leading to decreased physical activity during adolescence and during adulthood.

This model has at least three limitations. First, numerous potential mediators were excluded (the emphasis was on fundamental movement skills as a potential mediator). Second, fundamental movement skills are likely to predict sports play and exercise during leisure time, but less likely to predict walking for transportation or daily physical activity at work. Therefore, its role as a potential mediator may be limited to leisure-time physical activity. Third, this model focused on individual-level characteristics. It did not take into account factors in the environment (such as parks and open spaces), which are known correlates of physical activity (Bauman et al., 2012), and which could increase physical activity in the disadvantaged neighbourhoods that benefit from them. As such, this model should be seen as conceptualizing the association between socioeconomic position and physical activity at the individual level in the framework of life course epidemiology, not as a comprehensive model aiming to explain physical activity behaviour.

6.4 — Education as a key determinant of physical activity

We have studied education, income, and social class as predictors of physical activity. In the Canadian data we have analyzed, both education and income were included in the models. Although our aim was not to determine which of education or income was more strongly associated with physical activity, we found that education was associated with physical activity more consistently than income. This suggests that of the two, education may be a better predictor of physical activity. Education may be a better predictor of physical activity than income because physical activity has no direct economic cost, in its simplest forms (e.g. walking). Therefore, differences in incomes in and of themselves are unlikely to lead to wide differences in opportunities to participate in leisure-time physical activity, except perhaps for extreme poverty. Even then, as physical activity is free, poverty itself may not explain low levels of physical activity; they are more likely to be explained by other variables in the causal chain, such as lack of time for single mothers working two jobs.

We could hypothesize that education is a better predictor of physical activity based on Phelan and Link's theory of fundamental causes because education gives access to resources (such as knowledge) that enable higher levels of physical activity. Knowledge, it could be argued, enables higher levels of physical activity in three ways. First, by increasing awareness of the importance of physical activity for health. Second, by providing more choices of physical activities, in more settings, and perhaps in more enjoyable ways. Third, as education is generally gained early in life, more time in school might lead to more exposure to physical education classes, better mastery of fundamental skills, and more time to translate these skills into the specialized movement sequences required for sports play. This, in turn, leads to increased self-rated motor competency and higher levels of physical activity, according to Stodden et al. (2008).

We could also hypothesize that education is a better predictor of physical activity than income based on the work of Bourdieu (1978). As we have seen, in Bourdieu's work, cultural capital and the habitus are at the core of preferences towards physical activity. As both concepts are strongly tied to education, this provides more theoretical support for education being a key determinant of physical activity.

Empirically, this hypothesis is supported by Gidlow et al. (2006)'s systematic review of socioeconomic position and physical activity. In their review, "education produced the more stable relationships." Relationships for education were more stable than those seen for social class based on occupation, income, assets-based, or area-based measures.

6.5 — Limitations

We have already noted some limitations in each of the three articles we have included in this thesis. We will now discuss the limitations of this thesis as a whole.

One limitation of the body of research we have produced is our focus on one domain of physical activity (leisure time). It is generally accepted that there are four domains of physical activity: at work, during transports, during leisure time, and at home (also sometimes called "housework") (Bauman et al., 2006; Hallal et al., 2012). All four domains of physical activity are important, and an integrated approach to the promotion of physical activity should aim to increase overall daily physical activity across all domains.

Indeed, promoting physical activity in one domain at the expense of the others might fail to increase overall physical activity levels, failing to prevent overweight and obesity on a population level. For example, using data from six nationally representative surveys, we have found that between 1994 and 2005, although Canadian adults have become more active during leisure time and transports, they have become less active at work (Juneau and Potvin, 2010). We argued that while it may be encouraging to report that physical activity levels are rising by examining leisure-time physical activity only (Craig et al., 2004), time use studies have shown that leisure time accounts for only about 21% of adult's total time (Aguiar and Hurst, 2007). We underscored that leisure-time physical activity accounts for only a small portion (about 100 kcal•day^{-1}) of the energy adults expend daily in physical activities, with nonexercise activity thermogenesis (such as physical activity at work) accounting for most of the expenditure (Levine, 2007). We concluded that since most Canadian adults spend the majority of weekdays at work, declining levels of physical activity at work may explain the rising prevalence of overweight and obesity in Canada, even if levels of physical activity during leisure time and transports are increasing. Our findings highlighted the importance of promoting physical activity in all domains of life.

Unfortunately, although physical activity in all domains of life is important, domains outside leisure time have been much less studied, especially in relation to their life course association with socioeconomic position. We have included data for physical activity during transports and at work in our analysis of the 1970 British birth cohort, where it was available. However, our analysis of Canadian data focused on leisure-time physical activity only. In addition, we have not included data for physical activity at home (housework) in any of our analysis. This limitation is very common in this body of literature, perhaps because most studies relied on secondary analysis of preexisting datasets, which did not aim to measure physical activity in depth and across all domains. This was reflected in our systematic review, in which the only domain of physical activity we highlighted was leisure-time physical activity, as few studies had measured physical activity in other domains.

Both our analyses of Canadian and British data were carried out as secondary analysis of preexisting databases. This introduced a number of limitations. First, for the Canadian dataset, the first measurement was carried out at age 8-9 years. Since measures were not available for birth or early childhood, sensitive periods for these ages might have been missed. Second, for both the Canadian and the British dataset, measures were not available for late adulthood and old age. Indeed, Canadians participants were last surveyed at age 22-23 years, and British participants were last surveyed at age 34 years. Therefore, the association between socioeconomic position early in life and physical activity into late adulthood and old age could not be studied. Third, education, income, and social class were not available as measures of socioeconomic position in both datasets (we used education and income in the Canadian dataset, and social class in the British dataset). This limits comparison between studies, and between indicators within each study. Finally, and this is a major point, these surveys were not designed to measure physical activity. Physical activity during leisure time is the only domain of physical activity that was measured in the Canadian dataset. Yet, it is only one of the four domains of physical activity. Our conclusions are thus somewhat limited to physical activity during leisure time. Lastly, physical activity data were collected using questionnaires that were not validated. Therefore, our results should be interpreted with caution, and confirmed in future research using measures of physical activity that are more valid and reliable.

In both our analyses of Canadian and British data, we have relied on self-reports of physical activity. Self-reports have been shown to overestimate true levels of physical activity (Prince et al., 2008). For example, based on self-reports, Cameron et al. (2007) estimated that 51% of the adult population in Canada is sedentary. In contrast, based on accelerometer results, Colley et al. (2011a) estimated that only 4.8% of Canadian adults aged 20 to 79 years are physically active. These two studies clearly show that self-reports overestimate the real prevalence of physical activity. Thus, it is likely that many inactive subjects in both datasets over-reported physical activity sufficiently to be considered physical active. Is this information bias differential or non differential? Perhaps subjects higher up the socioeconomic scale over-report physical activity more than others? Two studies suggest that they do not (Rzewnicki et al. 2003; Slootmaker et al., 2009).

Rzewnicki et al. (2003) examined over-reporting on the International Physical Activity Questionnaire (IPAQ). The study was carried out in Belgium. Subjects were fifty adults who had answered the IPAQ in a national telephone survey. Subjects were telephoned a second time for validation. A modified phone interview was used for the second call. There was substantial over-reporting: 75% of subjects reported less physical activity with the modified interview than with the IPAQ. Revised reports indicated that 50% fewer subjects met physical activity recommendations than originally believed, based on IPAQ reports. IPAQ thus produced substantial misclassification bias. However, over-reporting was not associated with work status, income, or education (Rzewnicki et al., 2003).

Slootmaker et al. (2009) examined disagreement in physical activity assessed by accelerometer and self-report. Subjects were 236 adolescents (aged 12-18 years) and 301 adults (aged 22-40 years). Self-reports were based on a validated questionnaire (the "Activity Questionnaire for Adolescents & Adults"). All subjects completed the questionnaire and wore an accelerometer for two weeks. There was over-reporting of physical activity in all age groups. Subgroup differences by education were examined. Highly educated adolescents reported more physical activity than adolescents with less education. However, accelerometers results showed the reverse was true (adolescents with low education were more physically active). In adolescents, this disagreement was greater among girls than boys. Among adults, there was better agreement between the two measures of physical activity, and no significant differences between educational levels were found. Thus, in this study, education was related to over-reporting of physical activity (on questionnaire) in adolescents only.

Overall, these two studies suggest that adult subjects higher up the socioeconomic scale do not over-report physical activity more than others. As this measurement error is independent of level of exposure (socioeconomic position), it is likely that our estimates of association were not biased (Gustafson, 2003).

A related potential limitation is that missing data randomness was not evaluated. Nonresponse bias may have been introduced if data were missing not at random (MNAR) (Little and Rubin, 2002). Data would have been MNAR if survey nonresponse to socioeconomic position (social class, education or income) and physical activity were related. Because of social desirability, perhaps low socioeconomic position respondents who performed no physical activity refused to give this information more often than others. This would have resulted in nonresponse bias. However, as we have just seen, studies have shown that over-reporting of physical activity is not related to socioeconomic position in adults (Rzewnicki et al., 2003; Slootmaker et al., 2009). This suggests that social desirability does not influence the reporting of physical activity differently across socioeconomic position strata, and provides some confidence that data were not MNAR. Another potential limitation related to missing data is attrition. Attrition reduces statistical power (Goodman and Blum, 1996). Low statistical power appeared not to have undermined our results, as many of the associations we have estimated were statistically significant, most likely because our samples were relatively large, despite attrition. However, differential attrition may have been a concern. Differential attrition occurs when characteristics of study participants who drop out differ systematically from characteristics of participants who do not drop out (De Keulenaer, 2008). Differential attrition by socioeconomic position has been reported in many longitudinal studies (Watson and Wooden 2004). Differential attrition may bias mean values, variance, and associations between variables, although this is not always the case (Goodman and Blum, 1996). Differential attrition by socioeconomic position has been not evaluated in our samples. Therefore, we do not know if differential attrition has biased our results, or to what extend. This is a limitation.

Another limitation of our original research is that physical activity was not measured during childhood or adolescence. While socioeconomic position is not associated with physical activity during childhood (Van Der Horst et al., 2007; Gustafson and Rhodes, 2006), this association has been found in adolescence (Stalsbergs and Pedersen, 2010). A better description of the trajectory of physical activity as it relates to socioeconomic position, and a more detailed analysis of the pathways linking socioeconomic position and physical activity across the life course would have been possible, had physical activity during childhood and adolescence been included in the models.

In addition, our original research shares a common limitation with much of the research published in epidemiology. While we have studied socioeconomic position (in relation to physical activity), our analyses were not grounded in a deep theoretical understanding of the meaning of social class, education, or income (the measures of socioeconomic position we have used). To support our use of these measures, we have cited the work of Lynch and Kaplan (2000), Galobardes et al. (2006a; 2006b; 2007) and Link and Phelan (1995). While this work is often cited in epidemiology, we recognize that its theoretical basis may seem unsatisfactory or incomplete, from a sociological standpoint.

In our systematic review, only Medline and EMBASE were searched. The following databases were not searched: PsycINFO (psychological literature), Sociological abstracts (sociological literature), ABI Inform, Business Source Premier (business/management literature), EconLit (economic literature), Social Service Abstracts (social work and social service literature), and SPORTDiscus (sports and exercise literature). This is a limitation, and perhaps studies were missed. During our search, we found 10,619 papers. We retained 48 based on full text. We reviewed their reference list and we found only two papers which had not already been found. This suggests the databases that were not searched did not contain many relevant studies. This is somewhat reassuring, although this remains a limitation of our systematic review. Once duplicate analyses of the same dataset were excluded, 42 publications remained. Of those, 26/42 (61.9%) found a significant association. Let us pretend two more papers were not found. If both had found a significant association, the proportion would have become 28/44 (63.6%). If both had not found a significant association, it would have become 26/44 (59.1%). In both cases, our results would not have changed markedly and our conclusions would have remained essentially the same.

Another limitation of our systematic review is that methodological quality assessment focused on only three criteria: (1) Was childhood socioeconomic position assessed prospectively? (2) Was socioeconomic position during adulthood included in the statistical analysis? (3) Was a validated instrument used to measure of physical activity? The focus of the quality assessment was relatively narrow, comprising only three highly relevant indicators of quality. Some systematic reviews in this field of research have used more general criteria to assess methodological quality, such as clearly stated objectives and research questions, selection bias, attrition bias, and confounding. Prince et al. (2008) and Warburton et al. (2010) have used a modified Down and Black checklist (Down and Black, 1998). Lubans et al. (2010) created their own checklist based on STROBE and CONSORT statements (von Elm et al., 2007; Moher et al., 2001). Lai et al. (2014) used the PRISMA statement (Liberati et al., 2009). Other authors have combined general criteria with specific criteria related to their object of research (Gidlow et al., 2005; Samitz et al., 2011). Still others, the majority, have used no criteria and have not assessed quality at all (Trost et al., 2002; Galobardes et al., 2004; Marshall et al., 2004; Pollitt et al., 2005; Galobardes et al., 2006; Bize et al., 2007; Senese et al., 2009; Stalsberg and Pedersen, 2010; Lee et al., 2011; Van Remoortelet al., 2012). We chose to focus on specific criteria because even in studies in which overall quality is high, if the specific criteria we identified were not respected, results would have been prone to substantial measurement and analytical error. Therefore, we opted for a narrow but highly relevant set of criteria which would be sensitive in discriminating among our pool of studies. Nevertheless, we recognize that a combination of general and specific criteria, as Gidlow et al. (2005) and Samitz et al. (2011) have used, would have provided additional insight into the overall methodological quality of the studies we have systematically reviewed.

Our choice of quality criteria could also be criticized, especially criterion (2): Was socioeconomic position during adulthood included in the statistical analysis? We argued in section 5.2.5 ("Measurement for only two points in time") that this was important from both a theoretical and a methodological standpoint. We will expand here on its theoretical importance. From a theoretical standpoint, this criterion is important because life course epidemiology aims "to elucidate biological, behavioural, and psychosocial processes that operate across an individual's life course, or across generations, to influence the development of disease risk" (Kuh et al., 2003). Central to life course epidemiology is the concept of chains of risk, of which social chains of risk are especially relevant to our research. According to Kuh et al. (2003), "Socioeconomic factors at different life stages may operate either via social chains of risk or by influencing exposures to causal factors at earlier life stages that form part of long term biological or psychological chains of risk." Therefore, any analysis of socioeconomic position spanning the life course should include measures of socioeconomic position both during childhood and adulthood. It would not be consistent with life course epidemiology theory to analyze the association between an outcome in adulthood and a risk factor during childhood without accounting for the trajectory of this risk factor and its tracking throughout the life course. As we have argued elsewhere (Juneau et al., 2015), in any study of socioeconomic position rooted in life course epidemiology, socioeconomic position during adulthood should be included in the statistical analysis as an independent, interacting, mediating, or confounding variable, based on the conceptual model that guides the study. We insist that research rooted in life course epidemiology should begin with a clear conceptual model consistent with this field's theory, and that if this model includes the study of socioeconomic position, that this variable should be included in the statistical analysis for each measurement point across the life course.

A potential limitation of our original research is that confounders such as health behaviours, work characteristics, and socio-demographic characteristics were not included in the models. These variables were not included in the models because they were conceptualized as mediators, not confounders (Baron and Kenny, 1986; MacKinnon et al., 2007). As mediators, these risk factors were considered to be proximal to physical activity, and mediating the association between socioeconomic position during childhood and physical activity during adulthood. Thus, in our models, health behaviours such as smoking, psychosocial exposures at work, marital status, and number of children in the household would represent the mechanisms that underlie the association we have observed between socioeconomic position during childhood and physical activity during adulthood. If we had considered these variables as confounders, and if we had controlled for them, we would have biased our results towards the null. Indeed, controlling for a mediator (or intermediate variable) on a causal path from exposure (socioeconomic position during childhood) to outcome (physical activity during adulthood) leads to overadjustment bias (Schisterman et al., 2009). Overadjustment bias biases estimates of the total causal effect towards the null (underestimation) (Schisterman et al., 2009).

It follows that another limitation of our original research is that potential mediators were not included in the analysis. Using structural equation modeling, we have described crude associations between socioeconomic position across the life course and physical activity during adulthood, according to three theoretical models in life course epidemiology. Our analysis was useful in pointing to which life course model best represented theses associations. It also allowed us to highlight the benefits of using structural equation modeling over other techniques traditionally used in life course epidemiology to analyze life course data. However, our analysis was not useful in explaining the pathways through which socioeconomic position (presumably) influences physical activity. It is likely that these associations have several mediators. Studying these mediators could help us understand the relationship between socioeconomic position and physical activity. This is an important question, and future research should aim to answer it. However, this was not the question we aimed to answer. We aimed to determine (1) if there was an association and (2) which life course model best represented it. We did not aim to explore how this association was mediated.

Another limitation is that sex differences were not formally tested. Patsopoulos et al. (2007) and Nieuwenhuis et al. (2011) have noted that sex differences are often claimed in medical research even though formal tests of interaction have not been carried out. Indeed, formal tests of interaction are recommended in subgroup analyses to test for sex differences (Brookes et al., 2004). These tests should be formulated a priori, as part of the analytical plan (Patsopoulos et al., 2007). In our analysis of the Canadian dataset, different life course models fit the data best for men and woman, suggesting that the patterns of associations between socioeconomic position during childhood and physical activity during adulthood may be specific to each gender. However, as this was not tested formally, this hypothesis should be confirmed in future research.

Yet another potential limitation is that zero-inflated Poisson models were used to analyze the UK data, whereas linear models were used to analyze the Canadian data. In both datasets, the outcome for physical activity was skewed right and had excess zero-valued observations. In the Canadian paper, we addressed this by using a square root transformation. In the UK paper, we addressed this by using a zero-inflated Poisson model, because one of the reviewers of the journal in which it was published required it. There were one benefit and two limitations of this approach. The benefit is that using a zero-inflated Poisson model is likely to have provided more valid estimates of regression coefficients, as it respected the underlying processes that generated excess zeros. The first limitation is that using a zero-inflated Poisson model prevented us from estimating indirect associations between social class at birth and physical activity at age 34 years in the accumulation of risk models (models 1 and 2). Indeed, indirect effects cannot be estimated with count variables and Poisson models in MPLUS, as these models require the MONTECARLO command to be used, and MPLUS cannot estimate indirect effects when the MONTECARLO command is used. The second (and perhaps most important) limitation is that the only fit indices available for reporting were the Akaike information criterion (AIC) and the Bayesian information criterion (BIC). We reported both. Guidelines for structural equation modeling recommend reporting of the x2 goodness-of-fit statistic (Schermelleh-Engel et al. 2003, Tabachnick and Fidell, 2007). The x2 goodness-of-fit test statistic is sensitive to sample size: the null hypothesis, which indicates the model fits the data, is almost always rejected if sample size is high enough (Tabachnick and Fidell, 2007). In sensitivity analyses, we ran the models with quintiles of physical activity score as the outcome, which allowed the x2 goodness-of-fit statistic to be computed. In doing so, we have indeed found that the null hypothesis was rejected in every model, even when other fit indices indicated acceptable fit. Therefore, we based our comparison of model fit on AIC and BIC, as they are meant by design to be used to compare competing models (lower AIC and BIC values indicate better fit) (Schermelleh-Engel et al. 2003, Tabachnick and Fidell, 2007). However, AIC and BIC are not commonly used (McDonald and Ringo Ho, 2002) and there are no clear cutoffs to interpret them. More commonly used indices are root mean squared error of approximation (RMSEA) and its 90% confidence interval, comparative fit index (CFI), and Tucker Lewis index (TLI). These indices have clear cutoffs and guidelines (Boomsma, 2000; McDonald and Ringo Ho, 2002; Tabachnick and Fidell, 2007). In our analyses of Canadian data, we have used linear models, so we could use these indices, as we were more interested in testing and comparing model fit than in obtaining highly accurate estimates of associations. Nonetheless, in view of the issues discussed above, this could be seen as a limitation.

A final limitation is path coefficients between predictors (social class, education or income) and outcomes (physical activity) in our structural equation models may be seen not to conform strictly to life course epidemiology theory. For example, in the UK dataset, for leisure-time physical activity, in men, the accumulation of risk model with additive effects fit the data best. In the counts portion of this model, path coefficients all reached statistical significance. In this portion of the model, path coefficients for social class at birth and at ages 10 and 30 years were in the expected direction (higher social class, more physical activity—these path coefficients were negative because social class is inherently reverse coded).

However, path coefficients for social class at ages 5 and 34 years were in the opposite direction (higher social class, less physical activity). One could argue that to agree fully with life course epidemiology theory, all path coefficients in this model should have been in the expected direction. This was not the case. Therefore, while model fit indicated that the accumulation of risk model with additive effects represented this relationship best, path coefficients did not conform strictly to life course epidemiology, and their interpretation may suggest a different relationship. Stronger conclusions could have been drawn from our models if all path coefficients had been in the expected direction.

6.6 — Research recommendations

Based on the limitations of our own research, as well as common limitations we have found in this body of literature, we make the following recommendations for future research:

(1) Future research should measure physical activity using validated methods. We recommend using accelerometers, an objective measure of physical activity. Accelerometers are more valid and reliable than questionnaires. They are increasingly used, making comparisons across studies possible. As more and more studies use accelerometers, pooled analyses will also eventually become possible. Accelerometers measure whole-day physical activity, across all domains (and not just leisure-time physical activity). Their main drawback is their cost, so when budgets are limited, we recommend using them in subsamples.

(2) Future research should measure childhood socioeconomic position prospectively, during childhood. Retrospective measures are associated with recall bias, leading to poor measurement of exposure.

(3) Future research should include socioeconomic position during adulthood in their statistical analyses. In fact, we recommend including as many time points as possible in the analysis along the "independent variable path" in a structural equation model. We also recommend that this structural equation model be based on one of the conceptual models proposed in the theory in life course epidemiology.

The ideal study design for examining the associations between socioeconomic position across the life course and physical activity during adulthood would include:

(1) Multiple indicators of socioeconomic position (education, income, and occupation at minimum)

(2) Measures of whole-day physical activity across all domains. Of the methods currently available (and feasible for studies of daily living), doubly labeled water has the highest validity and reliability. If cost prohibits using doubly labeled water, accelerometers should be used.

(3) Measures at multiples points in time, starting at birth. At least one measure during childhood, one during adolescence, one during early adulthood, one during middle adulthood, one during late adulthood, and one in old age.

(4) Measures of socioeconomic position and physical activity at each point in time.

(5) Measures of potential mediating factors (such as motor competency) at each point in time.

(6) A clear theory of causation and hypotheses based on life course epidemiology theory.

(7) A multivariate statistical analysis framework based on "life course path analysis."

6.6 — Generalizability

Research into socioeconomic position across the life course and physical activity during adulthood has been carried out in Western, high-income countries, mostly. Our own research using Canadian and British data add to this evidence base from Western, high-income countries. Our results, and the results of our systematic review, apply to high-income countries and should not be overly generalized, especially to low-income countries, or countries with other cultural backgrounds. For example, in China, evidence shows that the odds of engaging in leisure-time physical activity and active commuting increases markedly with age for both sexes, resulting in an increase in overall physical activity levels as people get older (Bauman et al., 2011). In contrast, in a study of 25,639 men and women residing in Norfolk, UK, Barnett et al. (2014) found that retirement was associated with a decline in overall levels of physical activity. In this study, physical activity at work and during transports decreased, and this decrease was not compensated for by an increase in housework and physical activity during leisure time. So, overall, retirement seems to be associated with an increase in physical activity in China, and a decrease in the UK. This appears to be a cultural difference, and it would suggest a different pattern of association for socioeconomic position across the life course and physical activity in Western and Eastern cultures. Therefore, our conclusions should be generalized to Eastern countries. Finally, this body of literature has also focused on the general, healthy populations. Its conclusions might not apply to individuals with diseases and disabilities.

6.7 — Policy implications for public health

Based on the results of this thesis, the following implications could be proposed for public health policy aiming to increase physical activity levels:

(1) Policy-makers could improve the average socioeconomic position of the population (e.g. it is likely that a more highly educated population will be more physically active)

(2) Policy-makers could improve the socioeconomic position of those at the bottom of the social hierarchy (this would have the added benefit of reducing the gap between those at the bottom and those at the top in terms of physical activity and of health)

(3) Policy-makers could improve the socioeconomic position of children (this is likely to benefit both physical activity and socioeconomic position later in life, as both are associated with socioeconomic position during childhood)

There are two important caveats to these implications. First, it is implied that the associations we have measured are causal. This has not been proven, although an important criterion for causality has been respected in our own research (temporality, i.e. low socioeconomic position measured during childhood precedes low physical activity measured during adulthood) (Hill, 1965; Susser, 1991; Rothman and Greenland, 2005). Second, it should be noted that Rothman (1993) and Wilcox (2001), consecutive Editors-in-Chief of *Epidemiology*, have discouraged the practice of discussing the policy implications of epidemiological data in research reports. Rothman (1993) argued that: "Making good health policy is complicated. It involves weighing individual rights, liberties, and economic issues along with epidemiologic findings." Rothman also argued that authors who become policy advocates based on their own research may be inclined to defend their findings and to abandon "the self-critical attitude to which scientists should aspire" (Rothman, 1993). Wilcox (2001) chose to maintain Rothman's policy, and added that: "few epidemiologists really understand the process of policy-making." Therefore, the implications we have just proposed should be considered with restraint.

6.8 — Implication for health promotion practice

The evidence we have produced in this thesis may be used to inform health promotion practice; although it is likely that health promotion practitioners will need to adapt this evidence to their needs and local context (Potvin et al., 2011; Juneau et al., 2011).

Interventions in health promotion can be broadly classified into three categories: those targeting high-risk individuals, those targeting the whole population, and those targeting vulnerable populations (Rose, 1985; Rose, 1992; Frohlich and Potvin, 2008). Briefly, the "high-risk" approach seeks to truncate the risk distribution, by identifying high-risk individuals and offering them protection or treatment (Rose, 1985). In contrast, the population approach seeks to control the determinants of incidence in the population as a whole (Rose, 1985). Lastly, the vulnerable populations approach aims to reduce social inequalities in health by focusing on subgroups that, because of shared social characteristics, are at higher risk of risks (Frohlich and Potvin, 2008).

For example, a "high-risk" intervention aiming to increase physical activity might focus on cardiovascular patients referred by their physician after screening for low self-efficacy, high job strain, high stress, and low intention to exercise, which are all established individual-level correlates of physical activity (Bauman et al., 2012). In contrast, a whole population intervention might consist in building new recreation facilities in public spaces such as parks, as access to recreation facilities is an established environmental correlate of physical activity (Bauman et al., 2012). Lastly, a vulnerable population intervention might pay all school fees for adolescents in low income households, therefore increasing mean educational attainment in this population, and exposing these adolescents to more physical activity through physical education classes in school.

In this thesis, we have identified socioeconomic position during childhood as a correlate of physical activity during adulthood. Thus, low socioeconomic position becomes a defining characteristic for "high-risk" individuals, while also being a characteristic of a vulnerable population. Therefore, increasing socioeconomic position during childhood might not only increase physical activity, but also lower this vulnerable population's "risk of risks" (Frohlich and Potvin, 2008), contributing to a reduction in social inequalities in health.

Thus the vulnerable groups approach seems especially suited, and we suggest that health promotion practitioners who operate with limited budgets and who are expected to implement effective interventions with measurable effects should frame their intervention in low socioeconomic position children and adolescents in a vulnerable groups framework. Interventions framed in the vulnerable populations approach should be intersectoral and participatory (Frohlich and Potvin, 2008). Indeed, for physical activity, the concerns of low socioeconomic position children and adolescents (or of their parents) might differ substantially from those of health promotion practitioners. Such intervention would need to be adapted to the local context, which is paramount for health promotion practice (World Health Organization, 1986; Poland et al., 2008). To do so, health promotion practitioners might want to supplement the quantitative evidence produced in this thesis with additional evidence, perhaps of qualitative nature, as others have done (for a collection of case studies, see Juneau et al., 2011).

6.9 — 3 examples of interventions in Canada

We have argued that to increase physical activity levels, interventions should focus on socioeconomic position during childhood. We have also argued that these interventions have the added potential to reduce social inequalities. We will now review three examples of intervention in Canada that aimed to increase physical activity during childhood. In doing so, based on the evidence available, we will try to determine if they are likely to reduce social inequalities over the long term.

The first intervention is the Canadian Children's Fitness Tax Credit. In its 2006 budget, the Government of Canada announced it intended to "help promote physical fitness among children by making it more affordable for Canadian families to register their kids in fitness activities" (Department of Finance, 2014). To do so, it introduced the Children's Fitness Tax Credit, which became effective in 2007. This new measure allowed parents to claim a non-refundable tax credit of up to $500 to register their child in a physical activity program. To be eligible, programs had to last 8 consecutive weeks or 5 consecutive days. They had to be supervised, and to improve cardio-respiratory endurance, plus one or more of: muscular strength, muscular endurance, flexibility, or balance (Spence et al., 2010). Spence et al. (2010) aimed to assess whether the awareness, uptake, and perceived effectiveness of this tax credit varied by household income among Canadian parents. They carried out an internet-based panel survey in March 2009 with a representative sample of 2,135 Canadians. The sample comprised 1,004 parents with children aged 2 to 18 years. Of those, 54.4% stated that their child participated in physical activity programs and 55.5% were aware of the tax credit. There was a graded association between quartiles of household income and child participating in organized physical activity. As household income rose from the lowest to the highest quartile, the proportion of children participating in organized physical activity increased: 40.1%, 45.9%, 59.0%, and 67.7% for each quartile, respectively. The gradient was more pronounced for awareness of the tax credit, with proportions of 38.8%, 56.5%, 62.5%, and 71.9% from the lowest to the highest quartile, respectively. A similar gradient (except for the highest quartile) was found for parents having claimed the tax credit in 2007 (28.2%, 36.9%, 55.7%, and 54.8%) and planning to claim it in 2008 (40.3%, 57.3%, 76.5%, and 69.5%). These associations remained significant in multivariate models adjusting for sex, age, and education of the parent, suggesting an effect of income independent of education. After adjustment, parents in the highest income quartile were 196% more likely to have claimed the tax credit in 2007 than those in the lowest quartile (OR = 2.96, 95% CI: 1.66-5.30, $p < 0.0001$). Furthermore, among parents who had claimed the tax credit, only 15.6% believed it had increased their child's participation in physical activity programs. The authors concluded that: "the tax credit appears to benefit the wealthier families in Canada." Similar results were found in a study that examined Canadian income tax returns data from 2007 to 2009 (Fisher et al., 2013). This study found that families earning more than $20,000 a year had between 4 and 30% higher odds of claiming the tax credit. Moreover, as family income increased, more tax credit was claimed (in dollar amounts). Families earning $100,000 to

$200,000 a year claimed $125 more, while families earning more than $200,000 a year claimed $250 more than those making less than $20,000. In the same study, national survey data was used to explore parent's perceptions of the tax credit: 65% of respondents reported that they had heard of the credit. The following variables all increased the odds of being familiar with the tax credit: being women, being aged 40-49 years, having a post-secondary education, and earning more than $40,000 annually. Among those familiar with the credit, 30.6% reported it motivated or encouraged them to register their child in physical activity or sport; 34.2% reported it made it easier to register their child in physical activity or sport; and only 15.2% reported it allowed them to register their child when they would not have otherwise being able to. In summary, parents with higher education and income were more likely to report being aware of the credit, and claimed more in dollar amounts (Spence et al., 2010; Fisher et al, 2013). In addition, since only 15.2% to 15.6% of parents believed it had increased their child's participation in physical activity programs, and since adolescents in higher socioeconomic position families are more active than those in low socioeconomic position families (Stalsbergs and Pedersen, 2010), it is possible that the tax credit had unintended consequences in high-income families whose children were already physical active; not increasing physical activity levels in these families, but providing additional economic advantage. Conversely, as the tax credit was non-refundable, parents who did not earn enough income were unable to claim it and did not benefit. Overall, this policy is likely to have increased social inequalities. In addition, there is evidence that it fails to increase physical activity in low-income families. Indeed, a recent randomized controlled study found no benefit of tax credits for low-income children (Dunton et al., 2015). Results showed that:

"tax credits did not significantly influence low-income children's rates of enrollment in after-school physical activity programs, frequency of participation, time spent in after-school physical activity programs, and overall moderate-to-vigorous intensity physical activity" (Dunton et al., 2015). The Canadian tax credit was increased to $1000 a year in 2014, potentially further driving social inequalities. However, perhaps due to numerous critics (Spence et al., 2010; Spence et al., 2012; Fisher et al, 2013;), the Canadian tax credit became refundable in 2015, so that low income families might benefit as well (Department of Finance, 2014).

The second intervention is funding for community organizations that offer physical activity programs targeted at adolescents (Tamminen et al., 2014). ParticipACTION, a national not-for-profit organization, has provided over $2,000,000 in funding to community organizations in Canada since 2008. In a qualitative study, Tamminen et al. (2014) interviewed 40 adolescents and 17 adults (organizers and instructors) from nine community organizations across Canada that received microgrants (up to $500) from ParticipACTION. Grants were provided to fund sports and physical activities targeted at adolescents, such as breakdancing, community sport, school sport, skating, and skiing. Interview results indicated that opportunities for physical activity programming would not have been possible without the microgrant funding; that microgrant funding was valuable in promoting physical activity for adolescents, that they afforded opportunities for adolescents to engage in new and/or nontraditional activities, and finally, that they improved organizational capacity (Tamminen et al., 2014). The authors concluded that: "Micrograts appear to be an effective mechanism for enhancing community capacity to provide PA opportunities for Canadian adolescents by helping to reduce financial barriers." To the extent that these microgrants were awarded to community organizations reaching adolescents in low socioeconomic position families, this intervention had the potential to reduce social inequalities in physical activity in the short term, as financial resources are more likely to be a barrier to participation in physical activity in such communities. However, the lack of information on the socioeconomic position of the participants in the activities, the qualitative nature of the evaluation of the program, and the lack of a long-term follow-up do not allow to conclude that this program reduced social inequalities in physical activity. Ideally, these limitations should be addressed using quantitative methods on larger samples.

The third intervention is school-based programs. Vander Ploeg et al. (2014) reported on a trial involving schools located in Edmonton, Alberta, Canada. This was a quasi-experimental trial with pre-post design and a parallel non-equivalent comparison group. The intervention, a school health program, was implemented in 10 schools in socioeconomically disadvantaged neighbourhoods. It was not implemented in the comparison group (20 schools also located in Edmonton with no involvement in health promotion). In intervention schools, the program aimed "to make the healthy choice the easy choice." It acted on social and physical environments; teaching and learning; healthy school policy; and partnerships and services. Activities included "a variety of non-competitive, enjoyable activity choices like Go-Girls/Go-Boys weekly intramurals, dance, skipping and yoga clubs, walking initiatives, and playground programs" (Vander Ploeg et al., 2014). Additional measures included improved access to after-school physical activity facilities, improved traffic safety to support active transportation, regular school-wide activities involving both students and parents, and a monthly school newsletters distributed to parents describing affordable, easily accessible, and seasonally appropriate activities for their children outside of school. Pedometer data (7 full days) were collected at baseline and two years later in grade five children from the 10 intervention and 20 comparison schools. Low-active, active, and high-active children were defined according to step-count tertiles. At baseline, students in the interventions schools were less active: they accumulated approximately 2,000 fewer steps per day than students from comparison schools — a 13.3% difference (10,827 vs. 12,265 steps/day, 95% CI: −2173; −703). Two years later, the relative difference in step-counts between intervention and comparison schools reduced from −15.5% to 0% among low-active students, from −13.4% to 0% among active students, and from −15.1% to −2.7% among high-active students. Overall, results for students in both groups of schools became similar (13,168 vs. 13,207 steps/day, 95% CI: −830; 751). Moreover, in subgroup analyses, students within the low-education and low-income groups in intervention schools experienced increases in physical activity greater than children within these groups in comparison schools. The authors thus reported that "this study provides compelling evidence that school-based health promotion reduces health inequities among children." However, two limitations should be noted. First, health was not measured. It was therefore inaccurate to conclude that health inequities were reduced. Only inequalities in physical activity were reduced, as measured in steps taken per day. Second, risk factors cluster in disadvantaged groups (Frohlich and Potvin, 2008). As students in these intervention schools are likely to face a disproportionate burden of health risk, increasing their physical activity is less likely to improve their health markedly. Indeed, perhaps not surprisingly, students in intervention schools were more overweight and obese, and this intervention had no effect on body weight (Vander Ploeg et al., 2014). Therefore, social inequalities in body weight were not reduced. Overall, it is too early to conclude that such interventions can reduce social inequalities in health over the long term.

We have just reviewed three examples of interventions that aimed to increase physical activity in children. A tax credit (Department of Finance, 2014), community funding (Tamminen et al., 2014), and school-based programs (Vander Ploeg et al., 2014). The tax credit was likely to increase social inequalities, whereas the other two interventions had the potential to reduce social inequalities in physical activity (although this remains to be rigorously evaluated over the long term). However, if we adopt a point of view rooted in the social determinants of health, we may hypothesize that none of these interventions are likely to reduce social inequalities in physical activity and in health over the long term. Indeed, none has improved the social determinants of physical activity in children from disadvantaged backgrounds. Ironically, the only intervention that focused on a social determinant (the tax credit) was formulated in such a way that those at the bottom of the economic hierarchy did not benefit, while those at the top benefited the most. The other two interventions focused on physical activity itself, while targeting low socioeconomic position children. The theory of fundamental causes suggests that in doing so, they will not reduce social inequalities in health over the long term, as they have not intervened on the root causes of low physical activity in these children; namely, their social conditions (Link and Phelan, 2005). To reduce social inequalities in physical activity and in health, action on their social determinants is needed, as the World Health Organization called for in its landmark 2008 report "Closing the gap in a generation: Health equity through action on the social determinants of health" (CSDH, 2008).

SECTION 7 — CONCLUSION

Physical activity extends life (Paffenbarger et al., 1986) and enhances health (Warburton et al., 2006). Yet, according to accelerometer results, only 4.8% of Canadians aged 20 to 79 years are physically active (Colley et al., 2011a). The public health burden of physical activity is not limited to Canada, and worldwide, physical inactivity is attributable for 3.2 million deaths each year (6% of all deaths), making it the 4th leading risk factor for global mortality (World Health Organization, 2009).

What causes people to engage in, or to avoid physical activity? Physical activity is a complex behaviour, with many correlates at the individual, social, and environmental levels (Bauman et al., 2012). Among the correlates of physical activity, socioeconomic position shows some of the strongest and most consistent associations (Trost et al., 2002; Seefeldt et al., 2002). These associations are well documented cross-sectionally, for both adolescence (Stalsbergs and Pedersen, 2010) and adulthood (Gidlow et al., 2006).

Are these associations purely cross-sectional? Or is there a long-lasting, life course association between socioeconomic position early in life and physical activity during adulthood? If there is a life course association, to what extent is it mediated by socioeconomic position during adulthood? Are both associations independent and additive? Or is the association for adolescence entirely mediated by socioeconomic position during adulthood?

To answer these questions, in this thesis, we have systematically reviewed the evidence on socioeconomic position early in life and physical activity during adulthood. We have also reviewed the methodological limitations most commonly found in this body of literature and we have made recommendations to strengthen future research. Finally, we have also applied these recommendations to our own research examining the association between socioeconomic position across the life course and physical activity during adulthood.

In carrying out this research, we have analyzed data from two large, nationally representative prospective cohorts: one with UK data (the 1970 British birth cohort) and one with Canadian data (the National Longitudinal Survey of Children and Youth). We have used structural equation modeling to compare competing models in life course epidemiology. In doing so, we have underscored three benefits of structural equation modeling over traditional regression-based techniques, namely: 1) all associations between any number of variables in the model can be estimated at once; 2) indirect associations can be estimated; 3) competing models can be compared based on goodness of fit statistics and a formal test of significance (for nested models).

The results of our systematic review and of our two original research papers suggest that the pattern of associations between socioeconomic position across the life course and physical activity during adulthood is best represented by the accumulation of risk model with additive effects. That is, socioeconomic position at each point of the life course seems to be associated with physical activity during adulthood directly, irrespective of later exposure (an independent association) and also indirectly through socioeconomic position later in life (mediation).

How can we explain this association between socioeconomic position early in life and physical activity during adulthood? Fundamental movement skills may mediate this association. There is evidence that low socioeconomic position during childhood is associated with development delays in fundamental movement skills (Goodway et al., 2013). Based on this observation and on Stodden et al.'s (2008) developmental model of physical activity, we hypothesize that low socioeconomic position during childhood launches the child on a life course of low physical activity and increased risk of unhealthy body weight, which would feedback continuously into diminishing levels of physical activity throughout the life course, leading to low levels of physical activity during adulthood.

Based on the research reviewed for this thesis, and our own findings, we have proposed a theoretical model linking socioeconomic position during childhood and physical activity during adulthood within a life course perspective (Figure 4). According to this model, socioeconomic position during childhood is associated with physical activity during adolescence and adulthood. This association is mediated by mastery of fundamental movement skills during childhood. Thus, high or low socioeconomic position during childhood may contribute to launching the child on two opposite life courses of physical activity. High socioeconomic position during childhood would increase the likelihood of mastering fundamental movement skills during childhood, leading to increased physical activity during adolescence and during adulthood. On the contrary, low socioeconomic position during childhood would result in poor mastery of fundamental movement skills during childhood, leading to decreased physical activity during adolescence and during adulthood. This theoretical model thus illustrates the association between socioeconomic position during childhood and physical activity during adulthood from a life course perspective, using fundamental movement skills as a mediator. A potential avenue for future research is to validate this model, and to explore the role of fundamental movement skills as a mediator of the association between socioeconomic position during childhood and physical activity during adulthood.

Finally, we have highlighted the implications of these findings for public health policy and health promotion practice. We have also briefly reviewed three examples of interventions aiming to increase physical activity levels in children in Canada. To increase physical activity levels, policy-makers could improve the average socioeconomic position of the population, the socioeconomic position of those at the bottom of the social hierarchy, or the socioeconomic position of children. This last option is perhaps the most promising: it is likely to benefit both physical activity and socioeconomic position later in life, as both are associated with socioeconomic position during childhood. It is also likely to reduce social inequalities in health. On a more micro level, health promotion practitioners could frame their interventions in a vulnerable population approach, which, in this case, merges with the high-risk approach (Rose, 1985; Frohlich and Potvin, 2008). If they choose this approach, their intervention should be intersectoral and participatory (Frohlich and Potvin, 2008), as the concerns of low socioeconomic position children and adolescents (or of their parents) might differ substantially from those of health promotion practitioners. Our brief review of interventions that aimed to increase physical activity levels in children in Canada suggests that they are unlikely to reduce social inequalities in physical activity and in health over the long term, as they have not improved the social determinants of children in low socioeconomic position families.

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APPENDIX 1 — SOCIOECONOMIC POSITION DURING CHILDHOOD AND PHYSICAL ACTIVITY DURING ADULTHOOD: A SYSTEMATIC REVIEW

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Juneau CE, Benmarhnia T, Poulin AA, Côté S, Potvin L. Socioeconomic position during childhood and physical activity during adulthood: a systematic review. Int J Public Health. 2015 Nov;60(7):799-813.

APPENDIX 2 — SOCIAL CLASS ACROSS THE LIFE COURSE AND PHYSICAL ACTIVITY AT AGE 34 YEARS IN THE 1970 BRITISH BIRTH COHORT

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Juneau CE, Sullivan A, Dodgeon B, Côté S, Ploubidis GB, Potvin L (2014) Social class across the life course and physical activity at age 34 years in the 1970 British birth cohort. Ann Epidemiol 24(9):641-7.

APPENDIX 3 — TRENDS IN LEISURE-, TRANSPORT-, AND WORK-RELATED PHYSICAL ACTIVITY IN CANADA 1994-2005

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Juneau CE, Potvin L. Trends in leisure-, transport-, and work-related physical activity in Canada 1994-2005. Prev Med. 2010 Nov;51(5):384-6.

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REVIEW

Socioeconomic position during childhood and physical activity during adulthood: a systematic review

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Abstract

Objectives A growing body of evidence links socioeconomic position early in life and physical activity during adulthood. This systematic review aimed to summarize this evidence.

Methods Medline and EMBASE were searched for studies that assessed socioeconomic position before age 18 years and physical activity at age ≥18 years. Studies were rated according to three key methodological quality criteria: (1) was childhood socioeconomic position assessed prospectively? (2) Was socioeconomic position during adulthood included in the statistical analysis? (3) Was a validated instrument used to measure of physical activity?

Results Forty-two publications were included. Twenty-six (61.9 %) found a significant association between socioeconomic position early in life and physical activity during adulthood. Twenty-one studies met at least two methodological quality criteria. Among those, the proportion was higher: 15/21 (71.4 %). Associations were of weak to moderate strength, positive for physical activity during leisure time, and negative for transports and work.

Conclusions The bulk of the evidence supports the notion that there is a life course association between socioeconomic position early in life and physical activity during adulthood. Studies using more rigorous methodology supported this conclusion more consistently.

Keywords Public health · Epidemiology · Physical activity · Longitudinal studies · Socioeconomic position · Systematic review

Introduction

In 2009, the World Health Organization ranked physical inactivity as the 4th leading risk factor for global mortality. It was estimated that physical inactivity is responsible for 3.2 million deaths each year, or 6 % of all deaths (World Health Organization 2009). Increasing population levels of physical activity thus hold much promise for public health. This task is challenging, as physical activity is a complex behavior, with many correlates at the individual, environmental, and social levels (Bauman et al. 2012). At the social level, socioeconomic position is a key correlate of physical activity (Trost et al. 2002). Indeed, systematic reviews have found cross-sectional associations between socioeconomic position and physical activity during adolescence (Stalsberg and Pedersen 2010) and during adulthood (Gidlow et al. 2006). That is, low socioeconomic position during adolescence is associated with low levels of physical activity during adolescence (Stalsberg and Pedersen 2010), and low socioeconomic position during adulthood is associated with low levels of physical activity during adulthood (Gidlow et al. 2006).

This raises a question: Is this association is purely cross-sectional, or is there a long-lasting, life course association

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between socioeconomic position early in life and physical activity during adulthood? This seems plausible, as socioeconomic position early in life has been associated in systematic reviews with three health outcomes during adulthood closely related to physical activity: cardiovascular disease (Pollitt et al. 2005), obesity (Senese et al. 2009) and physical capability levels (Birnie et al. 2011). Moreover, in a systematic review (Gidlow et al. 2006), physical activity during adulthood was found to be associated with education, an indicator that reflects, at least in part, socioeconomic position during adolescence and early adulthood (Galobardes et al. 2007). We aimed to systematically review and summarize the evidence linking socioeconomic position early in life and physical activity during adulthood. We hypothesized that the bulk of the evidence would support the notion that there is indeed a long-lasting, life course association between socioeconomic position early in life and physical activity during adulthood.

Methods

Search strategy

Medline (1947–2014 October week 4) and EMBASE (1974–2014 week 43) were last searched on October 30, 2014 with no language or date restrictions for studies that assessed socioeconomic position early in life and physical activity during adulthood. Search and screening of title, abstract, and full text for inclusion were carried out by two independent investigators. Discrepancies were solved by mutual agreement. A broad range of keywords related to physical activity, socioeconomic position, and the life course was used (Electronic supplementary material). Reference lists of all included studies were hand searched for additional studies.

Scope of the search and selection criteria

"Early in life" was defined as age lower than 18 years. We chose the term "early in life" to refer to both childhood and adolescence and to avoid any confusion with "childhood socioeconomic position" being interpreted as occurring only during ages 0–12 years (other reviews of childhood socioeconomic position and health outcomes later in life have also included ages 0–17 years; see Pollitt et al. 2005; Senese et al. 2009; Birnie et al. 2011). Adulthood was defined as age ≥18 years. Socioeconomic position was defined as a fundamental cause granting access to key resources that can be used to avoid health risks and adopt protective strategies (Link and Phelan 1995). Measures of socioeconomic position included social class, education, income, household amenities, perception of wealth, and area-based measures. Physical activity was defined as bodily movement produced by the contraction of skeletal muscle that increases energy expenditure above the basal level (U.S. Office of the Surgeon General 1996). All types and measures of physical activity were included. Studies were included if (1) they assessed socioeconomic position at least once for childhood or adolescence (age <18 years) and (2) they measured physical activity during adulthood (age ≥18 years). Studies that used education as the sole measure of socioeconomic position were excluded because a systematic review already reviewed its association with physical activity (Gidlow et al. 2006). Studies that focused on symptomatic population (e.g., cardiovascular patients) were also excluded. All study designs were considered.

Data extraction

Key methodological characteristics and results of each study were recorded in an Excel database. These included first author, country, date of publication, data source, sample size, age, and measures at each point in time across the life course, and magnitude and direction of the associations. Physical activity outcomes were grouped into two categories. The first category was "all types and measures of physical activity." This category included leisure-time physical activity, physical activity at work, physical activity during transports, physical housework, heavy gardening, free-living 24-h physical activity monitoring by accelerometry, cardiorespiratory fitness tests, musculoskeletal fitness tests, and physical activity diaries. The second category was a subcategory of the first. This category was "leisure-time physical activity only." It included self-reports of physical activity during leisure time, exercise, and sports. Studies that had the outcomes "moderate-to-vigorous" or "vigorous" leisure-time physical activity were also included in this category. We chose to consider leisure-time physical activity as a separate outcome because (1) its scope is easily understood and well defined, (2) it has a long history of research in public health (Paffenbarger et al. 1978), (3) public health recommendations traditionally have focused on leisure-time physical activity (U.S. Office of the Surgeon General 1996), and (4) it was the most commonly reported outcome. Data extraction was carried out by two investigators. After extraction, discrepancies were solved by mutual agreement.

Data analysis

Our original aim was to carry out a meta-analysis. However, after a preliminary review, we judged that meta-analysis would not be appropriate, because studies were highly heterogeneous (Lau et al. 1998; Egger et al. 2002;

Higgins and Green 2011). Important methodological differences were noted among studies. Notably, (1) the age for which childhood socioeconomic position was measured ranged 0–17 years; (2) childhood socioeconomic position was assessed using 12 different indicators; (3) physical activity was measured using 42 different instruments; (4) 16 different statistical techniques were used; (5) 47 different confounding variables were used. Therefore, we choose not to aggregate study results into a single estimate. Instead, we reported proportions of studies that found a significant association. We reported proportions for men and women combined, and stratified by sex. When available, we reported magnitude and direction of significant associations. For direction of associations, in some cases, the outcome was reverse coded (e.g., physical "inactivity"). For example, Regidor et al. (2004) found that low father social class during childhood was significantly associated with more physical inactivity over age 60 years in women. This was considered a positive association nonetheless, as the underlying interpretation is that women whose father had high social class were more active.

Quality assessment

Based on a preliminary review of study methodology, methodological quality assessment focused on three key study characteristics: (1) Was childhood socioeconomic position assessed during childhood in a prospective study design? Assessing childhood socioeconomic position during childhood is likely to provide more valid estimates. Indeed, retrospective recall of social class during childhood is less valid: published estimates of agreement with historical records range from 53.7 % (Batty et al. 2005) to 80 % (Berney and Blane 1997); (2) Was socioeconomic position during adulthood assessed and included in the multivariate model of physical activity during adulthood, either as an independent, interacting, mediating, or confounding variable? The association of socioeconomic position during adulthood with physical activity during adulthood is well established (Gidlow et al. 2006). Therefore, any association between socioeconomic position early in life and physical activity during adulthood not accounting for socioeconomic position during adulthood may be an artifact of the tracking of socioeconomic position early in life into adulthood (Corcoran 1995). Thus, not including socioeconomic position during adulthood in the model is likely to overestimate the real association between socioeconomic position early in life and physical activity during adulthood. (3) Was physical activity measured using validated methods? In this sample of studies, this included questionnaires with documented validity or reliability, accelerometers (a computerized, portable, objective measure of physical activity), or physical fitness tests (also an objective measure). Studies that referred to any documentation on the reliability or validity of the measurement tool were classified as "yes", regardless of how valid the instrument was. This criterion should therefore not be interpreted as meaning that the instrument used had high validity, although overall, it is likely that studies that used validated methods measured physical activity more accurately than those that did not.

Results

Result of the search

A total of 10,619 papers were found; 653 were retained based on title only. Of those, 135 were retained based on abstract and 48 were retained based on full text. Their reference lists were reviewed and contained two papers which had not already been found (Kimm et al. 2002; Popham and Mitchell 2006). When two papers used data from the same cohort, the older was excluded. Eight studies were thus excluded (Kuh and Cooper 1992; Yang et al. 1996; Brunner et al. 1999; Lawlor et al. 2004, 2005; Wray et al. 2005; Schooling et al. 2008; Walters et al. 2009). This review therefore includes 42 studies. Table 1 presents key characteristics of methodology, a summary of results, and direction of associations. Additional details of methodology and results are show in the Electronic supplementary material.

Measurement of socioeconomic position

All 42 studies assessed socioeconomic position. Eight studies assessed socioeconomic position only once, before age 18 years. The remainder (34 studies) assessed socioeconomic position at least twice: once before age 18 years and once for adulthood. Assessment early in life took place at ages 0 (birth) to 17 years. Eleven different indicators were used: the father's social class, the father's education, the mother's education, the mother's social class, the highest of either parents' social class, the highest of either parents' education, the presence (or absence) of certain household amenities, income, whether the family was perceived as wealthy, family access to a car, neighborhood socioeconomic level, and attendance to a fee paying school. Measurement during adulthood took place for ages 18–79 years. Fourteen different indicators were used: the subject's own education, social class, employment status, income, area-based measures of socioeconomic level, house ownership, car ownership, the household's highest social class, the partner's social class, wealth, job insecurity, skin color, pension arrangements, and perceived family economy.

Table 1 Key characteristics of methodology, summary of results, and direction of associations in the 42 studies included in this systematic review of socioeconomic position before age 18 years and physical activity at age ≥18 years

First authors (year of publication) country	Measurement SEP early in life	Adulthood SEP included analysis?	Validated measure of PA?	Quality score	Result summary	Direction of association
Mann et al. (2013) UK	Prospective	Yes	Yes	3	No associations between the father's social class at birth and sport, occupational, commuting, and household physical activity	Men and women combined LTPA: no association Transport: no association Work: no association Household: no association
Osler et al. (2001) Denmark	Prospective	Yes	Yes	3	No associations between the father's education at age 3–17 years and leisure-time physical activity age 19–31 years	Men LTPA: no association Women LTPA: no association
Poulton et al. (2002) New Zealand	Prospective	Yes	Yes	3	Low parental social class from birth to age 15 years significantly associated with lower cardiorespiratory fitness at age 26 years for men and women. Downward social mobility between 0–15 years and 26 years significantly associated with lower cardiorespiratory fitness at age 26 years for men and women	Men and women combined CRP: positive association
Barnekow-Bergkvist et al. (1998) Sweden	Prospective	Yes	Fitness: yes Transport: no LTPA: no	2 or 3	Father in manual work significantly associated with stronger two-hand lift and weaker standing balance at age 33 years for men only. Working mother (for men) and father in manual work (for women) significantly associated with more sport activities at age 33–36 years	Men LTPA: negative association CRF: no association MSF: positive association Women LTPA: negative association CRF: no association MSF: no association
Silverwood et al. (2012) UK	Prospective	Yes	Cycling: no	2 or 3	Upward social mobility significantly associated with more sedentary behavior during the working day and less walking for men only	Men
			LTPA: yes		Upward social mobility significantly associated with more leisure-time physical activity for men and women	LTPA: positive association
					Downward social mobility significantly associated with less sedentary behavior, more walking, and less leisure-time physical activity for men and women	Transport: negative association
					Upward educational mobility significantly associated with more sedentary behavior during the working day, less walking, and more leisure-time physical activity for men and women	Work: negative association
					Downward educational mobility less sedentary behavior during the working day (for men and women), more walking (for men only), but less leisure-time physical activity (for women only)	Women LTPA: positive association
					Low father education at age 6 years significantly associated with less sedentary behavior during the working day, more walking, less leisure-time physical activity (for men and women) and more cycling (women only)	Transport: negative association
					Low father's social class at age 4 years significantly associated with less sedentary behavior during the working the day for men only, more walking, and less leisure-time physical activity at age 36 years for men and women	Work: negative association

Table 1 continued

First authors (year of publication) country	Measurement SEP early in life	Adulthood SEP included analysis?	Validated measure of PA?	Quality score	Result summary	Direction of association
Aarnio et al. (2002) Finland	Prospective	No	Yes	2	Self-employed father at age 16 years significantly associated with higher odds of persistently inactive status from ages 16 to 18 years for men only. Self-employed mother at age 16 years significantly associated with lower odds of persistent exerciser status from ages 16 to 18 years for men only	Men LTPA: positive association Women LTPA: no association
Beunen et al. (2004) Belgium	Prospective	No	Yes	2	Higher father education at age 18 years significantly associated with higher sport and leisure-time indexes at age 40 years. Higher father's social class at age 18 years significantly associated with higher leisure-time index at age 40 years	Men only LTPA: positive association
Bratteby et al. (2005) Sweden	Prospective	No	Yes	2	High mother education at age 21 years significantly associated with lower total energy expenditure, activity energy expenditure, and physical activity level at age 21 years	Men and women combined Whole-day: negative association
Cleland et al. (2009) Australia	Retrospective	Yes	Yes	2	Highest parent's education at ages 0–12 years significantly associated with decreasing fitness and persistently unfit status from ages 9–15 to 26–36 years. High mother education and medium father education at ages 0–12 years significantly associated with persistently fit status from ages 9–15 to 26–36 years. Persistently high socioeconomic position and upward social mobility from ages 0–12 to 26–36 years significantly associated with less decreasing and more increasing activity and fitness at age 26–36 years	Men LTPA: positive association Women LTPA: no association Men and women combined CRF: positive association
Hart et al. (2008) UK	Prospective	Yes	No	2	No associations between the father's social class at age 10–39 years and usual daily activities at age 30–59 years for men and women	Men Whole-day: no association Women Whole-day: no association
Huurre et al. (2003) Finland	Prospective	Yes	No	2	Manual father social class at age 16 years significantly associated with less leisure-time physical activity at age 22 years for men only	Men LTPA: positive association Women LTPA: no association
Juneau et al. (2014) UK	Prospective	Yes	No	2	Social class at ages 0, 5, 10, 30, and 34 years were associated with physical activity at age 34 years, although the magnitude and the direction of the associations for social class at each age varied by physical activity outcome and by sex	Men LTPA: positive association Transport: no association Work: negative association Women LTPA: positive association Transport: negative association Work: negative association
Kimm et al. (2002) USA	Prospective	No	Yes	2	Black skin color at age 8–9 years associated with a 100 % decline in leisure-time physical activity levels by age 16–17 years (remaining so at 18–19 years). Low parental education at age 8–9 years significantly associated with low leisure-time physical activity at age 18–19 years in white and black girls	Women only LTPA: positive association

Table 1 continued

First authors (year of publication) country	Measurement SEP early in life	Adulthood SEP included analysis?	Validated measure of PA?	Quality score	Result summary	Direction of association
Kvaavik et al. (2012) Norway	Prospective	Yes	No	2	No associations between the father's education or the mother's education at age 11–15 years and leisure-time physical activity at ages 13–17, 23–27, 31–35, and 38-42 years	Men and women combined LTPA: no association
Osler et al. (2007) Denmark	Retrospective	Yes	Yes	2	No association between social class during childhood and walking, running, and biking at age 46–69 years	Men Composite: no association Women Composite: no association
Osler et al. (2008) Denmark	Prospective	Yes	No	2	No associations between the father's social class at birth and walking, running, and biking at age 51 years for men	Men only Composite: no associations
Sagatun et al. (2008) Norway	Prospective	No	Yes	2	High father income at age 17–18 years significantly associated with more leisure-time physical activity at age 18–19 years in ethnic Norwegian and ethnic minority women. Low mother education at age 17–18 years significantly associated with less leisure-time physical activity at age 18–19 years in ethnic Norwegian women only	Men LTPA: no association Women LTPA: positive association
Salonen et al. (2011) Finland	Prospective	No	Yes	2	High father social class at birth significantly associated with higher frequency of leisure-time physical activity at age 57–70 for men only	Men LTPA: positive association Women LTPA: no association
Svedenkrans et al. (2013) Sweden	Prospective	No	Yes	2	Highest parent's education, social class, and income at age 7–17 years significantly associated with higher cardiorespiratory fitness at age 18–26 years	Men only CRF: positive association
Taverno Ross et al. (2014) USA	Prospective	No	Yes	2	Foreign-born at age 14.9 ± 1.6 years significantly associated with less moderate-to-vigorous leisure-time physical activity at age 25.3 ± 1.6 years for men only	Men LTPA: positive association Women LTPA: no association
Telama et al. (2009) Finland	Prospective	No	Yes	2	Low father education at age 12–18 years significantly associated with less leisure-time physical activity across the life course up to age 40–46 years for men and women	Men LTPA: positive association Women LTPA: positive association
Azevedo et al. (2008) Brazil	Prospective	Not specified (unclear, classified as no)	Yes	1	Family income at birth, persistently low income, and downward income mobility from birth to age 22–23 years significantly associated with leisure-time sedentary lifestyle at age 22–23 years for men and women	Men LTPA: positive association Women LTPA: positive association
Bell and Lee (2006) Australia	Retrospective	No	Yes	1	No significant associations between the highest parent's social class during childhood and physical activity at age 22–27 years. Women only	Women only Composite: no association

Table 1 continued

First authors (year of publication) country	Measurement SEP early in life	Adulthood SEP included analysis?	Validated measure of PA?	Quality score	Result summary	Direction of association
Blane et al. (1996) UK	Retrospective	Yes	No	1	No significant associations between the father's social class during childhood and recreational exercise at age 35–64 years	Men only LTPA: no association
Elwell-Sutton et al. (2011) China	Retrospective	No	Yes	1	No significant associations between parental possessions during childhood and leisure-time physical activity over age 50 years	Men and women combined LTPA: no association
Heraclides et al. (2008) UK	Retrospective	No	Yes	1	No associations between the father's social class during childhood and walking, cycling, sports, gardening activities, housework, and house maintenance physical activity at age 45–68 years for men and women	Men Composite: no association Women Composite: no association
Hillsdon et al. (2008) UK	Retrospective	Yes	No	1	Low childhood socioeconomic position significantly associated with lower walking, cycling, heavy gardening, and physical exercise at age 60–79 years for women	Women only Composite: positive association
Leino et al. (1999) Finland	Retrospective	Yes	No	1	No associations between the highest parent's education during childhood and exercise at age 21–30 years	Men LTPA: no association Women LTPA: no association
Lynch et al. (1997) Finland	Retrospective	No	Yes	1	Poor or middle score on index of socioeconomic conditions at age 10 years significantly associated with less leisure-time physical activity at age 42–60 years (men only)	Men only LTPA: positive association
Oygard and Anderssen (1998) Norway	Prospective	No	No	1	No associations between the father's education at age 11–14 years and leisure-time physical activity at age 23–26 years for men and women	Men LTPA: no association Women LTPA: no association
Popham and Mitchell (2006) UK	Retrospective	Yes	No	1	Having attended a fee paying school during childhood significantly associated with more leisure-time physical activity at age 18–64 years for women only	Men LTPA: no association Women LTPA: positive association
Pudrovska and Anishkin (2013) USA	Retrospective	Yes	No	1	High family socioeconomic status at age 17–18 years significantly associated with more leisure-time physical activity at age 64–65 years for men and women	Men LTPA: positive association Women LTPA: positive association
Regidor et al. (2004) Spain	Retrospective	Yes	No	1	Low father social class during childhood significantly associated with more physical inactivity over age 60 years for women only	Men LTPA: no association Women LTPA: positive association

Table 1 continued

First authors (year of publication) country	Measurement SEP early in life	Adulthood SEP included analysis?	Validated measure of PA?	Quality score	Result summary	Direction of association
Salonna et al. (2008) Slovakia	Prospective	No	No	1	Low highest parent's education and low highest parent's social class at age 14–15 years significantly associated with less sport at age 18–19 years for women only	Men LTPA: no association Women LTPA: positive association
Tammelin et al. (2003) Finland	Prospective	No	No	1	No associations between for father social class at age 14 years and leisure-time physical activity at age 31 years for men and women	Men LTPA: no association Women LTPA: no association
Van de Mheen et al. (1998) Netherlands	Retrospective	Yes	No	1	Low father social class at age 12 years significantly associated with lower odds of frequent physical activity at age 25–74 years for women only No associations for "no physical activity" for men and women	Men LTPA: no association Women LTPA: positive association
Bowen (2010) USA	Retrospective	No	No	0	Low mother education, low father education, and manual father social class during childhood significantly associated with less physical activity over age 50 years	Men and women combined Composite: positive association
Heslop et al. (2001) UK	Retrospective	No	No	0	No associations between the father's social class during childhood and recreational exercise at age 35–64 years	Women only LTPA: no association
Suppli et al. (2013) Denmark	Retrospective	No	No	0	Low vigorous physical activity at age 15 years significantly associated with low vigorous physical activity at age 27 years only in participants with low socioeconomic position during childhood	Men and women combined LTPA: positive association
Kamphuis et al. (2013) Netherlands	Retrospective	No	No	0	No associations between the father's social class at age 12 years and leisure-time physical activity, sports, and transport-related physical activity at age 40–75 years for men	Men only Composite: no association
Kittleson et al. (2006) USA	Retrospective	No	No	0	No associations between the father's social class during childhood and physical training at age 26 years	Men only LTPA: no association
Ramsay et al. (2007) UK	Retrospective	No	No	0	Low father social class during childhood significantly associated with inactive lifestyle at age 52–73 years	Men only LTPA: positive association

The literature search was done without country or year restriction; *SEP* socioeconomic position, *PA* physical activity, *LTPA* leisure-time physical activity, *OR* odds ratio, *RR* relative risk, *CRF* cardiorespiratory fitness, *MSF* musculoskeletal fitness)

Measurement of physical activity

All 42 studies measured physical activity; 31 studies had only one outcome for physical activity; 11 had multiple. Physical activity was measured using 42 different instruments. Self-reported leisure-time physical activity (including exercise and sport participation) was the most common outcome (31 studies). Other outcomes included physical activity during transports, physical activity at work, cardiorespiratory fitness, musculoskeletal fitness, walking, cycling, heavy gardening, housework, accelerometry, activity diary, and ad hoc, composite measures based on physical activity in more than one domain of life.

Statistical analysis

Overall, 16 different statistical techniques were used. Logistic regression was the most commonly used technique (it was used in 13 studies). Other techniques included logistic random effects regression, ordinal logistic regression, stratified logistic regression, binomial regression, Poisson regression, multiple regression, generalized estimating equation models, stepwise multiple regression, ANOVA, ANCOVA, *t* test, χ^2 test, log multinomial regression, structural equation modeling, and latent class analysis. Likewise, there was much discrepancy in confounding variables. Age and sex were the most common confounders, but overall, 47 different variables were used as confounders.

Association with outcome "all types and measures of physical activity"

A significant association was found between socioeconomic position early in life and at least one measure of physical activity during adulthood in 26 of the 42 studies (61.9 %) (Table 2). This was true in 16 of the 31 studies that reported results for men (51.6 %), in 13 of the 27 studies that reported results for women (48.2 %), and in 5 of the 8 studies that reported results adjusted for sex (62.5 %).

Association with outcome "leisure-time physical activity"

A total of 31 studies reported results for leisure-time physical activity as a separate outcome. A significant association was found in 21 of these 31 studies (67.7 %) (Table 2). This held true for men in 14 out of 25 studies (56 %), for women in 12 out of 22 studies (54.6 %), and for sex-adjusted analyses in 1 out of 4 studies (25 %).

Magnitude and direction of associations

Most associations were weak to moderate. The strongest association reported was OR (95 % CI) = 2.45 (1.25–4.80) (Aarnio et al. 2002). The weakest significant association was OR (95 % CI) = 0.94 (0.90–0.99) (Hillsdon et al. 2008). Magnitude of associations should be interpreted with caution as methodology varied widely across studies (differences in measurement, statistical technique, and confounders may explain differences in magnitudes of associations). Direction of associations by sex are shown in Table 3 for outcomes reported in at least two studies (for clarity, outcomes reported in only one study and studies that used an ad hoc, composite measure based on physical activity in more than one domain are excluded from Table 3, as these cannot be readily compared). For leisure-time physical activity, for men, 13/25 studies (52 %) found a positive association (i.e., high socioeconomic position early in life, high physical activity during adulthood), 11/25 studies (44 %) found no association, and 1/25 study (4 %) found a negative association. For women, 11/22 studies (50 %) found a positive association, 10/22 studies (45.5 %) found no association, and 1/22 study (4.5 %) found a negative association. In sex-adjusted analyses, 1/4 study (25 %) found a positive association and 3/4 studies (75 %) found no association. Other outcomes were less studied. Only four studies measured cardiorespiratory fitness (Barnekow-Bergkvist et al. 1998; Poulton et al. 2002; Cleland et al. 2009; Svedenkrans et al. 2013). Poulton et al. (2002) and Cleland et al. (2009) adjusted for sex and found a positive association. Svedenkrans et al. (2013) studied men only. They found a positive association as well. Barnekow-Bergkvist et al. (1998) stratified results by sex and found no association. Therefore, overall, a positive association was found for cardiorespiratory fitness in 3/4 studies (75 %), whereas no association was found in 1/4 study (25 %). Only three studies reported results for physical activity at work as a separate outcome (Silverwood et al. 2012; Mann et al. 2013; Juneau et al. 2014). All three were carried out in recent years in the UK. Of those, one study found no association, and two studies found a negative association. The same three studies also reported results for physical activity during transports as a separate outcome. Similarly, one study found no association, and two studies found a negative association (although for women only in Juneau et al. 2014; no association was found for men in that study).

Methodological quality assessment

Of the 42 studies, 23 (54.8 %) measured childhood socioeconomic position during childhood in a prospective

Table 2 Summary of associations between socioeconomic position before age 18 years and physical activity during adulthood in the 42 studies included in this systematic review (the literature search was done without country or year restriction)

	Significant association	No association	Total	% significant
All studies				
All types and measures of physical activity	26	16	42	61.9
Leisure-time physical activity only	21	10	31	67.7
More rigorous methodology				
All types and measures of physical activity	15	6	21	71.4
Leisure-time physical activity only	12	3	15	80.0

Table 3 Direction of associations between socioeconomic position before age 18 years and physical activity during adulthood for outcomes reported in at least two studies, by sex (the literature search was done without country or year restriction)

	Positive association	No association	Negative association	Total	% positive
Men					
Cardiorespiratory fitness[a]	3	1		4	75.0
Leisure-time physical activity	13	11	1	25	52.0
Physical activity at work		1	2	3	0
Physical activity during transports		2	1	3	0
Women					
Cardiorespiratory fitness[a]	2	1		3	66.7
Leisure-time physical activity	11	10	1	22	50.0
Physical activity at work		1	2	3	0
Physical activity during transports		1	2	3	0

[a] Results for cardiorespiratory fitness were pooled for men and women in 3 of the 4 studies

study design. Nineteen (45.2 %) included socioeconomic position during adulthood in their statistical analysis. Twenty-one (50 %) measured physical activity using validated methods. Overall, five studies (11.9 %) met all three quality criteria; 16 studies (38.1 %) met two; 15 studies (35.7 %) met one; and six studies (14.3 %) met zero (Table 1).

Evidence from studies using more rigorous methodology

Overall, 21 studies met at least two of the three methodological quality criteria. This was considered a subset of studies using more rigorous methodology. In this subset, 15 studies (71.4 %) reported a significant association between socioeconomic position early in life and the outcome "all types and measures of physical activity" during adulthood. This was true for men in 12/16 studies (75 %), for women in 6/14 studies (42.9 %), and for sex-adjusted analyses in 3/5 studies (60 %). For the outcome "leisure-time physical activity only," a significant association was found in 12/15 studies (80 %). This was true for men in 10/12 studies (83.3 %), for women in 6/12 studies (50 %), and for sex-adjusted analyses in 0/2 studies (0 %).

Discussion

This systematic review aimed to summarize the evidence linking socioeconomic position early in life and physical activity during adulthood. We hypothesized that the bulk of the evidence would support the notion that there is indeed a long-lasting, life course association between socioeconomic position early in life and physical activity during adulthood. Overall, the results of this systematic review provided support for our hypothesis.

Using a broad set of keywords, we found 10,619 published studies. We retained studies of all designs that assessed socioeconomic position at least once early in life (age <18 years) and that measured physical activity during adulthood (age ≥18 years). A total of 42 studies were retained. Socioeconomic position before age 18 years and physical activity during adulthood were associated in 26 of the 42 studies (61.9 %). This proportion increased to 21/31 (67.7 %) when we focused on leisure-time physical activity only as the outcome. This proportion further increased in studies that met at least two of our three methodological quality criteria (prospective measurement of childhood socioeconomic position, statistical inclusion of socioeconomic position during adulthood, and use of a validated instrument to measure physical activity). In this subset of studies using more rigorous methodology, a significant association between socioeconomic position early in life and physical activity during adulthood was found in 15/21 studies (71.4 %) for all types and measures of physical activity and in 12/15 studies (80 %) for leisure-time physical activity only as the outcome. Associations were in the expected direction for leisure-time physical activity (i.e., high socioeconomic position early in life, high leisure-time physical activity during adulthood). Only one study found a negative association between these two variables (Barnekow-Bergkvist et al. 1998). Other outcomes were less studied. The evidence pointed to a positive association for cardiorespiratory fitness (3/4 studies) and to a negative association for physical activity during transports (2/3 studies) and at work (2/3 studies). Overall, these results suggest that (1) there is indeed a long-lasting, life course association between socioeconomic position early in life and physical activity during adulthood; (2) studies using more rigorous methodology supported this conclusion more consistently; (3) associations for leisure-time physical activity were found more consistently than for physical activity in other domains of life; and (4) direction of associations appeared to be positive for leisure-time physical activity and cardiorespiratory fitness and negative for physical activity during transports and at work.

Our results are in line with those of other systematic reviews that found associations between socioeconomic position early in life and health outcomes during adulthood (Senese et al. 2009; Pollitt et al. 2005; Birnie et al. 2011). Senese et al. (2009) systematically reviewed the literature on socioeconomic position during childhood and obesity during adulthood. They reported that 70 % of studies of females found decreasing obesity during adulthood with increasing socioeconomic position during childhood (this association was found for males in only 27 % of studies, however). Similarly, in their systematic review for cardiovascular diseases, Pollitt et al. (2005) found that "studies reviewed provided moderate support for the role of low early-life socioeconomic status and elevated levels of cardiovascular disease risk factors and cardiovascular disease morbidity and mortality." Lastly, in a meta-analysis, Birnie et al. (2011) found evidence that lower childhood socioeconomic position was associated with modest reductions in physical capability levels in adulthood. Taken as a whole, this body of literature seems to suggest that socioeconomic position early in life is consistently associated with health outcomes during adulthood.

We were hesitant to report the strength of the associations in the studies we systematically reviewed, for a number of reasons related to methodology. Methodology varied widely across studies: (1) most studies stratified results by sex, but some adjusted for sex, and one reported both stratified and adjusted results; (2) most studies assessed socioeconomic position twice, but some assessed it just once (early in life), and a few assessed it three times or more across the life course; (3) socioeconomic position before age 18 years was assessed using 11 different indicators; (4) there was no consistent age for assessment of socioeconomic position before age 18 years (assessment took place for ages 0–17 years) or during adulthood (assessment took place for ages 18–79 years); (5) socioeconomic position during adulthood was assessed using 14 different indicators; (6) physical activity was measured using 42 different instruments; (7) 16 different statistical techniques were used; and (8) 47 different confounding variables were used. No two studies used the same design: even in studies that used the same statistical technique, confounders, measurement of socioeconomic position, or measurement of physical activity were different. As strength of association is dependent on measurement and handling of data, study results should be compared with caution. For example, the strongest association reported was OR (95 % CI) = 2.45 (1.25–4.80) (Aarnio et al. 2002). In this study, there was thus an increased risk of "persistently inactive" status (a dichotomous variable defined as exercise 1–2 times a month or less for 3 years consecutively, at ages 16, 17, and 18 years). It was found in young men whose father was self-employed vs. upper level employee (reference category). Logistic regression was used, and the model was adjusted for smoking, alcohol use, breakfast eating, school type, school grade, and own perception of current health. Compare this with the weakest significant association reported, OR (95 % CI) = 0.94 (0.90–0.99) (Hillsdon et al. 2008). In that study, there was thus a lower risk of being more physically active (defined as an ordinal variable with four categories of increasing weekly hours spent in the following activities: brisk walking, cycling, heavy gardening, and leisure-time physical exercise such as tennis). It was found in women aged 60–79 years. Risk of being more physically active decreased as values on a composite indicator of childhood socioeconomic position increased (this indicator comprised, for childhood: father manual social class, no bathroom at home, no hot water at home, no car access, and shared bedroom). Ordinal logistic regression was used, and the model was adjusted for age, smoking, BMI, cardiovascular disease, respiratory disease, and adult socioeconomic position (including adult social class, housing tenure, car ownership, pension arrangements, and area-level deprivation). How can we explain the differences in results between these two studies? It could be the sample (young men vs. older women) or the country (Finland vs. UK), but it could also be the measure of socioeconomic position (self-employed father vs. composite indicator), the measure of physical activity (persistently inactive vs. a combination of walking, cycling, gardening, and leisure-time exercise), or the choice of confounders. Until there is more standardization in life course studies of socioeconomic position and physical activity, we believe that only a general, cautious interpretation of this body of literature is in order. We further believe that strengths of associations should not be compared directly and that meta-analysis would not be appropriate.

To improve standardization in future research, we suggest a number of guidelines. Future research should measure physical activity using validated methods. Of the 42 studies, we included in this systematic review, only 21 (50 %) did so. Validated questionnaires were often used. These are a step in the right direction, but validated questionnaires are still prone to significant measurement error. Indeed, systematic reviews have concluded that self-reports of physical activity are inaccurate (Prince et al. 2008), even when validated questionnaires are used (Lee et al. 2011). Therefore, the results obtained in the 21 studies included in this systematic review (50 % of our sample) that did not use validated methods to measure physical activity should be interpreted with caution. In addition, even when validated questionnaires were used, internal validity could have been improved by using objectives measures such as accelerometers. Accelerometers can be used in subsamples when budgets are limited. They are generally regarded as providing more valid estimates than questionnaires (Prince et al. 2008). However, they do readily not distinguish between domains of physical activity. Therefore, depending on the study objective, questionnaires may still be useful to assess separately physical activity during leisure-time, during transports, at work, and at home. Whenever possible, we recommend a combination of methods to measure physical activity in future research: objectives measures to obtain more valid estimates and questionnaires to assess physical activity in each domain of life separately. Some authors have done this (Silverwood et al. 2012; Mann et al. 2013; Juneau et al. 2014), but other have collapsed multiple domains of physical activity into one single composite measure (Bell and Lee 2006; Bowen 2010; Hart et al. 2008; Heraclides et al. 2008; Hillsdon et al. 2008; Kamphuis et al. 2013; Osler et al. 2007, 2008). For example, Hart et al. (2008) combined data on "usual daily activity" (i.e., work) and "physical activity during non-working time" (i.e., leisure time) into a single measure. These outcomes are generally associated with socioeconomic position in different directions (i.e., higher socioeconomic position, more physical activity during leisure time and less physical activity at work). Thus, perhaps not surprisingly, Hart et al. (2008) found no association between their composite measure of physical activity and socioeconomic position during childhood. A final reason to use validated questionnaires or accelerometers is to enable comparisons between studies. In our sample, studies that did not use validated questionnaires used their own ad hoc measure of physical activity. This made comparisons across studies difficult.

In addition, future research on life course socioeconomic position should assess childhood socioeconomic position during childhood in a prospective study design. While commonly done in life course research, assessing childhood socioeconomic position retrospectively during adulthood may involve substantial measurement error and recall bias. Indeed, published estimates of agreement between retrospective recall and historical records range from 53.7 % (Batty et al. 2005) to 80 % (Berney and Blane 1997). Berney and Blane (1997) collected information from 57 UK subjects aged 64–83 years and compared it with archive material of the same subjects' social circumstances recorded 50 years previously. Their sample comprised subjects from two historical cohorts. In the first cohort, 80 % of subjects recalled their father's occupation correctly. In the second cohort, 66 % of subjects did so. Batty et al. (2005) analyzed data from a cohort of 12,150 children who took part in a school-based survey in 1962. In this survey, information was collected about the father's occupation at birth (reported by the mother at birth) and the father's occupation during childhood (reported in 1962 at age 6–12 years by children). Between 2000 and 2003, a questionnaire was mailed to traced cohort members. A total of 7183 (63.7 %) persons responded to the mid-life questionnaire. Subjects recalled their father's occupation at birth correctly in 53.7 % of cases, and that of their father during their childhood (at age 6–12 years) in 61.4 % of cases. Of the 42 studies included in our systematic review, only 23 (54.8 %) assessed childhood socioeconomic position prospectively during childhood. The remainder measured it during adulthood using retrospective recall. The evidence we have briefly reviewed here suggests that these studies' results should be interpreted with caution.

Moreover, in future research, we recommend that investigators include socioeconomic position during adulthood in their statistical analysis. This variable should be included as an independent, interacting, mediating, or confounding variable, based on the conceptual model that guides the study, as the association of socioeconomic position during adulthood with physical activity during adulthood is well established (Gidlow et al. 2006). As socioeconomic position tracks across the life course (Corcoran 1995), any association between socioeconomic position early in life and physical activity during adulthood unadjusted for socioeconomic position during adulthood is likely to be overestimated. In addition, whenever possible, socioeconomic position and physical activity should be assessed at multiple points in time across the life course, as both may fluctuate. Finally, future research, if possible, should try to determine whether the association between socioeconomic position early in life and physical activity during adulthood is graded, to strengthen causal inference.

How can we explain the association between socioeconomic position early in life and physical activity, especially leisure-time physical activity, during adulthood? While a comprehensive answer is beyond the scope of this review, the literature on fundamental movement skills may shed some light on this question. Fundamental movement skills are basic motor skills. They include skills like running and hopping (locomotor skills), catching and throwing (object control), and balancing and twisting (stability) (Lubans et al. 2010). They are "considered to be the building blocks that lead to specialized movement sequences required for adequate participation in many organized and non-organized physical activities for children, adolescents and adults" (Stodden et al. 2008). Stodden et al. (2008) proposed that "fundamental movement skills competency interacts with perceptions of motor competence and health-related fitness to predict physical activity and subsequent obesity from childhood to adulthood." Thus, according to this literature, early childhood and adolescence may both be sensible periods for physical activity later in life (because fundamental movement skills are learned during early childhood and because they are refined into specialized movement sequences during adolescence). Systematic review evidence that low socioeconomic position during adolescence is associated with low physical activity during adolescence (Stalsberg and Pedersen 2010) supports this hypothesis. Systematic review evidence that school-based interventions focusing on physical activity, fitness, or fundamental movement skills increase physical activity later in life further support this hypothesis (Lai et al. 2014). More research is needed to test this hypothesis, and the potential role of fundamental movement skills as a mediator between low socioeconomic position early in life and low physical activity during adulthood.

A limitation of this systematic review is that nearly all studies were carried out in high-income countries (including 17 in Scandinavian countries and 10 in the UK). Therefore, their conclusions should not be overly generalized to others settings, especially to lower income countries.

In conclusion, the bulk of the evidence we have reviewed in this systematic review supported the hypothesis that there is a long-lasting, life course association between socioeconomic position early in life and physical activity during adulthood. This hypothesis was supported more consistently for leisure-time physical activity and in studies using more rigorous methodology. To strengthen methodology in future research, we recommend that researchers (1) measure physical activity using accelerometers in subsamples, (2) report results for each domain of physical activity separately, (3) assess childhood socioeconomic position prospectively during childhood, and (4) include socioeconomic position during adulthood in their statistical analysis.

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Original article

Social class across the life course and physical activity at age 34 years in the 1970 British birth cohort

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ABSTRACT

Purpose: To examine the associations between social class at ages 0, 5, 10, 30, and 34 years and physical activity at age 34 years using a novel approach to analysis of life course data.
Methods: We used structural equation modeling to compare three competing models in life course epidemiology: the accumulation of risk model with additive effects, the accumulation of risk model with trigger effect, and the critical period model. Data were from a nationally representative prospective cohort of 16,571 British men and women born in 1970. Outcomes were physical activity during leisure time, during transports, and at work.
Results: For all three domains of physical activity, for men and women, the accumulation of risk model with additive effects fit the data best. In this model, social class at ages 0, 5, 10, 30, and 34 years were associated with physical activity at age 34 years, although the magnitude and the direction of the associations for social class at each age varied by physical activity outcome and by sex.
Conclusions: Structural equation modeling appears to be a helpful tool in selecting among competing models in life course epidemiology.
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Introduction

A growing body of evidence suggests that poor socioeconomic conditions across the life course act cumulatively to increase the risk of cardiovascular diseases. Physical inactivity is a key cardiovascular risk factor, and its association with socioeconomic conditions across the life course has also been the focus of numerous studies [1–24]. Overall, 13 studies [1–13] have found a statistically significant association between socioeconomic conditions during childhood or adolescence and physical activity in adulthood; 11 have not [14–24]. Drawing on research into life course epidemiology and social inequalities in health, this body of literature has tended to focus on low socioeconomic conditions during childhood as the main causal variable, leisure-time physical activity during adulthood as the main outcome, and socioeconomic conditions during adulthood as either a confounding, intermediate, or interacting variable.

These studies' conflicting results may be explained by a common set of limitations we aimed to address in this study: different indicators of socioeconomic conditions have been used interchangeably across the life course (sometimes within the same study) [5,6,17,19,21], socioeconomic conditions during childhood were often measured retrospectively in cross-sectional designs [4,6,8,9,11,12,14,18,22,24], the ages at which socioeconomic conditions were measured varied widely [1–24], and socioeconomic conditions during adulthood were not always accounted for [2,3,7,8,13,14,17]. Moreover, the life course has been operationalized in most studies as only two points in time (one measurement during childhood and one during adulthood) [1–4,8–24]. Finally, most studies focused on leisure-time physical activity [1,2–4,6–9,11–17,19–24]. Physical activity in other domains of life, such as physical activity during transports or at work, was rarely considered.

This study aimed to address these limitations and to determine how social class across the life course is associated with physical activity during adulthood. Specifically, it aimed to integrate structural equation modeling with life course epidemiology theory to determine which life course model best explains the association between social class across the life course, and physical activity during adulthood. Three life course models were compared: the accumulation of risk model with additive effects, the accumulation of risk model with trigger effect, and the critical period model [25]. Briefly, in the accumulation of risk model with additive effects, each

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exposure increases the risk of exposure in the subsequent period and has an independent effect on the outcome (e.g., a lifelong of smoking). In the accumulation of risk model with trigger effect, each exposure increases the risk of exposure during the subsequent period, but only the last exposure triggers the outcome (e.g., injection drug use increasing risk of needle sharing and human immunodeficiency virus transmission). In the critical period model, exposure occurring during a period where susceptibility is greater has long-lasting and unalterable effects on the outcome (e.g., prenatal drug exposure). Based on the evidence of modest association with socioeconomic conditions during adulthood and weak or inconsistent association with socioeconomic conditions during childhood, we hypothesized that the accumulation of risk model with additive effects would best represent the association between social class across the life course and physical activity during adulthood.

Methods

Study design, setting, and participants

Data were from the 1970 British birth cohort ($n = 16,571$), a large, ongoing, nationally representative multidisciplinary cohort study. Data were collected at birth, and subjects were followed up successfully four times, at ages 5, 10, 30, and 34 years. Sample sizes (and response rates) at each follow-up were, respectively, 12,981 (78.34%), 14,350 (86.60%), 10,833 (65.37%), and 9665 (58.32%). In 1970 (at birth), data were collected using clinical records, interviews with parents, and a questionnaire completed by the attending midwife. In 1975 (age 5 years) and 1980 (age 10 years), information was gathered from children, their parents, and school teachers. In 1999 to 2000 (age 30 years) and in 2004 to 2005 (age 34 years), subjects answered questions about all major domains of life during face-to-face interviews. Ethical approval has been granted by the UK Medical Research Ethics Council before each data collection cycle of the 1970 British birth cohort.

Variables and measurement

Independent variables were social class at birth and at ages 5, 10, 30, and 34 years. Occupation, a measure of social class, was self-reported by parents during interviews at birth and when subjects were aged 5and 10 years. Occupation was also self-reported by subjects at ages 30 and 34 years during face-to-face interviews. For birth and ages 5 and 10 years, the highest parent's occupation was used as proxy. Occupations were categorized according to the Registrar General's classification into grades I (professional) to V (unskilled). At all ages, less than 2.6% of cases were from social class V (unskilled). Therefore, social classes IV (partly skilled) and V (unskilled) were merged. As grade III (skilled) is split into manual and nonmanual, occupation was thus a categorical variable with five ordered categories. Dependent variables were physical activity during leisure time, physical activity at work, and physical activity during transports. All were self-reported by subjects during interviews at age 34 years. For physical activity during leisure time and physical activity at work, a score representing 8 weeks of habitual physical activity was computed based on answers to three questions (for leisure-time physical activity) and two questions (for physical activity at work) (Appendix). These scores approximated energy expenditure: the higher the score, the more physically active the subjects were and the more energy they expended during leisure time or at work. Both scores were positively skewed and had a mode of 0. They were used separately as the dependent variable for physical activity during leisure time and physical activity at work, and zero-inflated Poisson models were used to account for the large number of zeros and positive skewness. Physical activity during transport was based on a single question about main form of transport. Subjects were asked: "What is your main form of transport?" Answers were: "car/motorcycle/moped," "public transport (i.e., buses and trains)," "cycling," "walking," "other," or "never goes out." Public transport was considered an active form of transport. Answers were recoded into "active" (public transport, cycling, or walking), "inactive" (car/motorcycle/moped), or "missing" (other, do not know, never goes out, or not applicable). Therefore, the main form of transport was a dichotomous variable ("active" or "inactive"). Sex was a dichotomous variable ("male" or "female"). It was a confounder, and all analyses were stratified by sex. Other confounders (for physical activity during transports only) were "time required to travel from home to work" (a categorical variable with eight ordered categories ranging from "under 5 minutes" to "2 or more hours") and "rating of local public transport services" (a categorical variable with five ordered categories ranging from "very good" to "very poor").

Statistical methods

Before analysis, all variables were examined for accuracy of data entry, missing values, and fit between their distributions and the assumptions of multivariate analysis [26]. Social class at age 34 years was missing for 1709 cases (17.8% of the sample). These were mostly "looking after home/family" (975 cases), "permanently sick/disabled" (228 cases), or "unemployed and seeking work" (193 cases). Similarly, social class was missing for 23.4, 14.9, 20.3, and 9.2% of the sample at ages 30, 10, 5, and 0 years, respectively. At age 34 years, leisure-time physical activity was missing for 32 cases (0.3% of the sample), physical activity during transports was missing for 106 cases (1.1% of the sample), and physical activity at work was missing for 1657 cases (17.2% of the sample). Missing data were imputed using full information maximum likelihood. A total of 41 outliers were detected in the sample. Outliers moved from social class IV-V to social class I between ages 30 and 34 years, or reported being in social class I with no education. They were deleted. This left 9624 subjects in the sample (4605 men and 5019 women).

Descriptive statistics were obtained using SPSS 18 (SPSS Inc, IL). Bivariate correlations among social class at ages 0, 5, 10, 30, and 34 years and physical activity were computed using Spearman's rho. Analyses were stratified by sex. For each sex and each physical activity outcome, three models were compared: the accumulation of risk model with additive effects (Fig. 1), the accumulation of risk model with trigger effect (Fig. 2), and the critical period model (Fig. 3). Structural equation models were computed using MPLUS 6.11 (Muthen & Muthen, CA). Each model was run separately with physical activity during leisure time, during transport, or at work as the dependent variable. These three outcomes have all been shown to be associated with socioeconomic conditions [27]. Therefore, they were all considered to be potential confounders. As such, the model with leisure-time physical activity as the outcome was adjusted for physical activity during transports and physical activity at work. The other two models were similarly adjusted. In addition, the model with physical activity during transports as the outcome was adjusted for two more potential confounders: "time required to travel from home to work" and "rating of local public transport services." To improve missing data imputation with full information maximum likelihood, for all estimations, the mean of each covariate was added (these were not included in the tested models).

Because zero-inflated Poisson models were used, we used the Akaike information criterion (AIC) and the Bayesian information criterion (BIC) to compare the fit of the three competing models (lower AIC and BIC values indicate better fit) [26,28]. Both AIC and

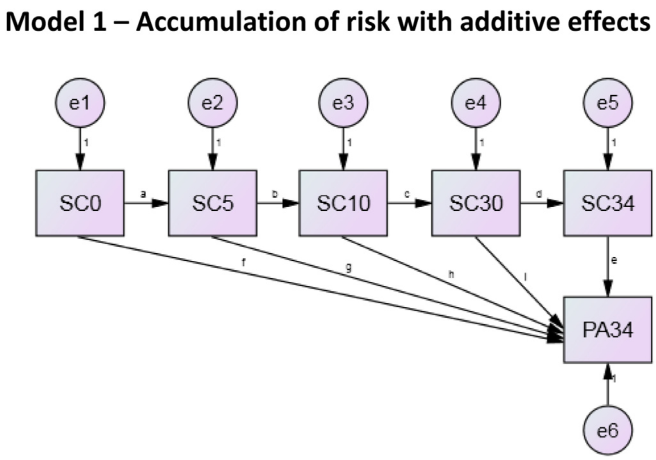

Fig. 1. Associations between social class across the life course and physical activity at age 34 years. This model reflects the accumulation of risk with additive effects hypothesis (all coefficients between social class across the life course and physical activity during adulthood are estimated). SC0-SC34 = social class at ages 0, 5, 10, 30, and 34 years. PA34 = physical activity at age 34 years.

BIC can be used to compare competing models, and these models do not need to be nested (in our comparison, models 2 and 3 were not nested) [26,28]. For all models, maximum likelihood estimation with robust standard errors was used to account for missing data.

Results

Descriptive statistics are shown in Table 1. Bivariate correlations are shown in Table 2 (men) and Table 3 (women).

For leisure-time physical activity, for men and women, model 1 fit the data best (Table 4). In this model, social class at all ages were significant predictors of social class later in life and of leisure-time physical activity at age 34 years (counts portion of the model). In addition, for men, social class at age 5 years was a significant predictor of leisure-time physical activity at age 34 years (logistic portion of the model), whereas for women, social class at all ages except at 5 years were significant predictors of leisure-time physical activity at age 34 years (logistic portion of the model).

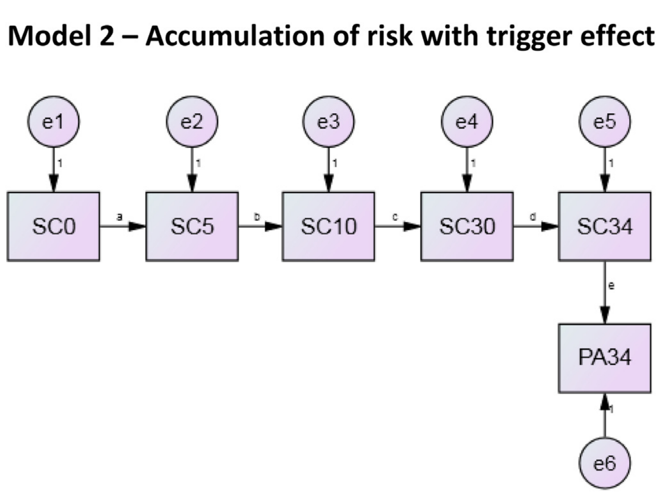

Fig. 2. Associations between social class across the life course and physical activity at age 34 years. This model reflects the accumulation of risk with trigger effect hypothesis (all coefficients between social class earlier in life and physical activity during adulthood are fixed to zero). SC0-SC34 = social class at ages 0, 5, 10, 30, and 34 years. PA34 = physical activity at age 34 years.

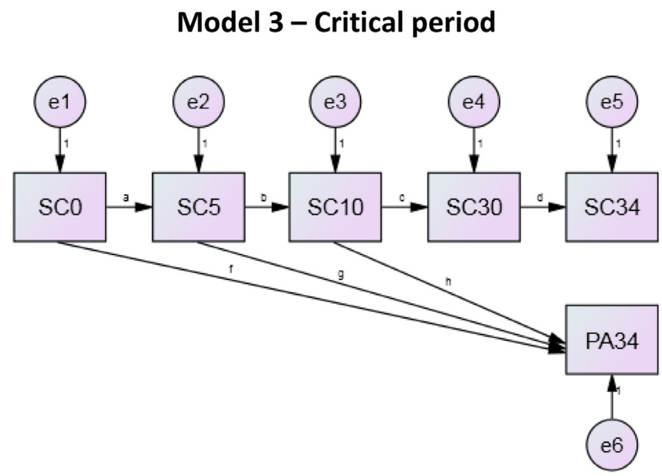

Fig. 3. Associations between social class across the life course and physical activity at age 34 years. This model reflects the critical period hypothesis (coefficients between social class during adulthood and physical activity during adulthood are fixed to zero). SC0-SC34 = social class at ages 0, 5, 10, 30, and 34 years. PA34 = physical activity at age 34 years.

For physical activity at work, for men and women, model 1 fit the data best (Table 5). In this model, social class at all ages were significant predictors of social class later in life. In men, social class at age 34 years was a significant predictor of physical activity at work (logistic and counts portions of the model), whereas social class at ages 30 years and at birth were significant predictors of physical activity at work only for the logistic portion of the model. In women, social class at ages 30 and 34 years were significant predictors of physical activity at work for both the logistic and the counts portion of the model.

For physical activity during transports, for men and women, model 1 fit the data best (Table 6). For men, social class was not a significant predictor of physical activity during transports. For women, social class at birth and at age 10 years were significant predictors of physical activity during transports.

Discussion

This study aimed to determine how social class across the life course is associated with physical activity during adulthood. Specifically, it aimed to integrate structural equation modeling with life course epidemiology theory to determine which life course model best explains the association between life course social class and physical activity during adulthood. Three life course models were compared: the accumulation of risk model with additive effects, the accumulation of risk model with trigger effect, and the critical period model. Three domains of physical activity were studied: physical activity during leisure time, physical activity during transports, and physical activity at work.

For all three domains of physical activity, the accumulation of risk model with additive effects fit the data best (model 1). In this model, social class at birth and at ages 5, 10, 30, and 34 years were associated with physical activity at age 34 years, although the magnitude and the direction of the associations for social class at each age varied by physical activity outcome and by sex.

In multivariate models, social class across the life course was associated with physical activity during transports for women, but not for men. Why would social class influence physical activity during transports for women and not for men? An explanation might be that, traditionally, men work outside the home, whereas women look after the children. Therefore, in lower social class

Table 1
Distribution (relative frequencies) of social class across the life course and physical activity at age 34 years for men ($n = 4605$) and women ($n = 5019$) in the 1970 British birth cohort

Variable	Men					Women				
	Age					Age				
	0	5	10	30	34	0	5	10	30	34
Social class										
I professional	12.2	6.1	6.1	6.8	7.1	12.0	5.6	5.4	3.3	4.0
II managerial technical	30.7	19.3	25.6	29.4	35.8	31.3	19.0	25.8	25.5	30.4
IIINM skilled nonmanual	9.4	12.6	17.9	10.6	10.0	9.1	12.5	18.3	27.5	24.0
IIIM skilled manual	31.3	30.4	25.6	26.0	27.9	31.4	30.5	25.0	5.3	4.6
IV-V partly skilled–Unskilled	7.1	11.5	9.9	10.0	10.5	7.1	12.1	10.5	9.3	11.0
Missing	9.3	20.1	14.9	17.2	8.8	9.0	20.4	15.0	29.2	25.9
Physical activity										
Exercises regularly										
Yes	—	—	—	—	78.0	—	—	—	—	79.5
No	—	—	—	—	21.6	—	—	—	—	20.2
Missing	—	—	—	—	0.7	—	—	—	—	0.3
Frequency of exercising										
Everyday	—	—	—	—	14.5	—	—	—	—	20.0
4–5 days a week	—	—	—	—	10.6	—	—	—	—	11.2
2–3 days a week	—	—	—	—	26.8	—	—	—	—	25.6
Once a week	—	—	—	—	17.8	—	—	—	—	15.9
2–3 times a month	—	—	—	—	6.6	—	—	—	—	5.1
Less often	—	—	—	—	1.9	—	—	—	—	1.7
Does not exercise	—	—	—	—	21.6	—	—	—	—	20.2
Missing	—	—	—	—	0.7	—	—	—	—	0.3
Got out of breath or sweaty										
Most times	—	—	—	—	40.1	—	—	—	—	25.7
Sometimes	—	—	—	—	18.6	—	—	—	—	24.9
Rarely	—	—	—	—	10.1	—	—	—	—	13.6
Never	—	—	—	—	9.3	—	—	—	—	15.3
Does not exercise	—	—	—	—	21.6	—	—	—	—	20.2
Missing	—	—	—	—	0.7	—	—	—	—	0.3
Main form of transport										
Car/Motorcycle/Moped	—	—	—	—	82.9	—	—	—	—	79.4
Public transport	—	—	—	—	9.4	—	—	—	—	10.8
Cycling	—	—	—	—	2.8	—	—	—	—	1.1
Walking	—	—	—	—	3.6	—	—	—	—	7.8
Missing	—	—	—	—	1.3	—	—	—	—	1.0
Use a computer at work										
Yes	—	—	—	—	63.9	—	—	—	—	56.0
No	—	—	—	—	28.3	—	—	—	—	18.2
Missing	—	—	—	—	7.8	—	—	—	—	25.4
How often use computer at work										
Daily	—	—	—	—	57.2	—	—	—	—	47.3
2–4 times/wk	—	—	—	—	3.6	—	—	—	—	5.6
Once a week	—	—	—	—	1.6	—	—	—	—	1.9
<Once a week	—	—	—	—	1.4	—	—	—	—	1.3
Does not use computer at work	—	—	—	—	28.3	—	—	—	—	18.2
Missing	—	—	—	—	7.8	—	—	—	—	25.8

The highest parent's social class for ages 0, 5, and 10 years. The subject's own social class for ages 30 and 34 years. All figures are percentages (relative frequencies).

households, if only one car is available, perhaps the man uses it, whereas the woman uses low cost (and physically active) forms of transport, such as walking. On the contrary, in more affluent households, where two cars may be available, perhaps the woman also uses a car, and is thus less physically active during transports. More research is needed to test this hypothesis and to determine

Table 2
Bivariate correlations among social class at birth and at ages 5, 10, 30, and 34 years and physical activity at age 34 years for men in the 1970 British birth cohort

	Social class					Physical activity		
	Birth	Age 5	Age 10	Age 30	Age 34	Leisure	Transport	Work
Social class								
Birth	1	—	—	—	—	—	—	—
Age 5	0.474*	1	—	—	—	—	—	—
Age 10	0.485*	0.661*	1	—	—	—	—	—
Age 30	0.258*	0.310*	0.305*	1	—	—	—	—
Age 34	0.249*	0.296*	0.307*	0.673*	1	—	—	—
PA								
Leisure	−0.080*	−0.048*	−0.086*	−0.103*	−0.107*	1	—	—
Transport	−0.011	0.004	−0.002	−0.055*	−0.042†	0.094*	1	—
Work	0.215*	0.235*,†	0.262*	0.518*	0.609*	−0.139*	−0.056*	1

PA = physical activity.
* Correlation is significant at the 0.001 level (two tailed).
† Correlation is significant at the 0.01 level (two tailed).

Table 3
Bivariate correlations among social class at birth and at ages 5, 10, 30, and 34 years and physical activity at age 34 years for women in the 1970 British birth cohort

	Social class					Physical activity		
	Birth	Age 5	Age 10	Age 30	Age 34	Leisure	Transport	Work
Social class								
Birth	1	—	—	—	—	—	—	—
Age 5	0.455*	1	—	—	—	—	—	—
Age 10	0.452*	0.669*	1	—	—	—	—	—
Age 30	0.221*	0.264*	0.283*	1	—	—	—	—
Age 34	0.215*	0.243*	0.238*	0.634	1	—	—	—
PA								
Leisure	−0.053*	−0.077*	−0.064*	−0.055*	−0.056*	1	—	—
Transport	0.076*	0.069*	0.087*	0.032	0.051†	0.085*	1	—
Work	0.136*	0.155*	0.153*	0.358*	0.438*	−0.009	0.053*	1

PA = physical activity.
* Correlation is significant at the 0.001 level (two tailed).
† Correlation is significant at the 0.01 level (two tailed).

why low social class is associated with more transport-related physical activity for women and not for men.

For physical activity at work, model 1 fit the data best; however, model 2 had only slightly worse data fit (especially for BIC). As others have noted, disentangling life course hypotheses is challenging, and analysis of empirical data may not always provide a clear-cut answer [29]. Although we believe that structural equation modeling can be a helpful tool in selecting among competing models in life course epidemiology, this underlines the importance of considerations other than statistical in favoring a model, such as prior knowledge of specific causal mechanisms [29].

This study addressed a number of limitations commonly found in the literature on life course socioeconomic conditions and physical activity during adulthood. We used the same indicator of socioeconomic conditions (social class) throughout the life course because each indicator measures a different facet of socioeconomic conditions [30] (others have used different indicators at different points in time) [5,6,17,19,21]. We measured childhood socioeconomic conditions during childhood in a prospective cohort design to avoid recall and other bias [31] (others have measured them retrospectively in cross-sectional designs) [4,6,8,9,11,12,14,18,22,24]. To pinpoint potential sensible periods, we measured socioeconomic conditions at five points across the life course, starting at birth, twice during childhood, and twice during adulthood (others have generally measured them only once during childhood and once during adulthood) [1–4,8–24]. We included socioeconomic conditions during adulthood in the statistical analysis as its association with physical activity is well established [32] (some have not) [2,3,7,8,13,14,17]. We included three outcomes for physical activity: physical activity during leisure time, at work, and during transports (others have studied leisure-time physical activity only) [1,2–4,6–9,11–17,19–24]. To the best of our knowledge, this study is the first to address all these limitations. Finally, another strength of this study is its results were obtained on a large nationally representative British cohort.

Table 4
Model fit and parameter estimates for structural equation models of social class at birth and at ages 5, 10, 30, and 34 years and leisure-time physical activity at age 34 years for men (n = 4605) and women (n = 5019) in the 1970 British birth cohort

	Model 1		Model 2		Model 3	
	Accumulation of risk (additive effects)		Accumulation of risk (trigger effect)		Critical period	
	Men	Women	Men	Women	Men	Women
Fit indices						
AIC	226912	219823	259615	256310	241510	250676
BIC	227195	220110	259795	256582	241742	250911
Parameter estimates						
Social class on social class at the subsequent period						
SC34 SC30	0.281*	0.208*	0.535*	0.701*	0.671*	0.695*
SC30 SC10	0.141*	0.175*	0.325*	0.267*	0.262*	0.200*
SC10 SC5	0.389*	0.434*	0.655*	0.660*	0.391*	0.369*
SC5 SC0	0.428*	0.450*	0.477*	0.464*	0.413*	0.373*
Social class on leisure-time physical activity at age 34 y (logistic portion of the model)						
PA SC34	0.072	0.171*	0.125*	0.058*	—	—
PA SC30	0.018	−0.062*	—	—	—	—
PA SC10	−0.012	0.106*	—	—	0.010	0.025
PA SC5	0.095*	−0.003	—	—	0.109*	0.030
PA SC0	0.054	0.088*			0.053	0.120*
Social class on leisure-time physical activity at age 34 y (counts portion of the model)						
PA SC34	0.168*	0.218*	0.128*	−0.188*	—	—
PA SC30	−0.207*	−0.284*	—	—	—	—
PA SC10	−0.199*	0.186*	—	—	−0.197*	−0.101*
PA SC5	0.236*	−0.243*	—	—	0.237*	−0.155*
PA SC0	−0.049*	0.050*	—	—	−0.053*	0.110*

PA = physical activity; SC = social class.
* $P < .05$ (two tailed).

Table 5
Model fit and parameter estimates for structural equation models of social class at birth and at ages 5, 10, 30, and 34 years and physical activity at work at age 34 years for men ($n = 4605$) and women ($n = 5019$) in the 1970 British birth cohort

	Model 1		Model 2		Model 3	
	Accumulation of risk (additive effects)		Accumulation of risk (trigger effect)		Critical period	
	Men	Women	Men	Women	Men	Women
Fit indices						
AIC	266650	278946	266803	279070	268244	279944
BIC	266933	279233	266983	279253	268476	280179
Parameter estimates						
Social class on social class at the subsequent period						
SC34 SC30	0.669*	0.689*	0.670*	0.692*	0.672*	0.695*
SC30 SC10	0.331*	0.275*	0.334*	0.279*	0.344*	0.283*
SC10 SC5	0.654*	0.656*	0.655*	0.660*	0.654*	0.657*
SC5 SC0	0.475*	0.459*	0.477*	0.464*	0.476*	0.457*
Social class on physical activity at work at age 34 y (logistic portion of the model)						
PA SC34	−0.993*	−0.760*	−1.305*	−0.968*	—	—
PA SC30	−0.457*	−0.349*	—	—	—	—
PA SC10	−0.101	−0.001	—	—	−0.305*	−0.144*
PA SC5	−0.021	−0.015	—	—	−0.163*	−0.108*
PA SC0	−0.081*	−0.034	—	—	−0.160*	−0.097*
Social class on physical activity at work at age 34 y (counts portion of the model)						
PA SC34	0.038*	0.028*	0.045*	0.047*	—	—
PA SC30	0.009	0.030*	—	—	—	—
PA SC10	0.006	0.009	—	—	0.011*	0.020*
PA SC5	0.008	0.003	—	—	0.010*	0.009
PA SC0	0.003	0.004	—	—	0.004	0.007

PA = physical activity; SC = social class.
* $P < .05$ (two tailed).

Nonetheless, some limitations must be noted in this study. Social class was based on the Register's General Classification of Occupation. This measure is widely used in epidemiologic research, but its validity is sometimes contested. As well, a fair amount of data were missing on social class, especially at ages 5 years (20.3% missing) and 30 years (23.5% missing). This was more than in another British study [24], where 7% to 15% of data were missing for social class. All measures of physical activity were self-reported. As the 1970 British birth cohort was not designed for exhaustive measurement of physical activity, its survey questions on physical activity during leisure time, during transports, and at work were not validated. Therefore, our estimates could be biased due to measurement error, and our results should be interpreted with caution. In addition, as leisure-time physical activity tends to be overestimated in self-reports, objective measures such as doubly labeled water, accelerometry, and VO_2 max tests would have provided better estimates [33]. These objective measures, however, are costly and time consuming, and are seldom used in large samples (of the 24 studies we have reviewed, only one did not rely on self-reports) [16]. Physical activity during childhood was not measured. As physical activity is relatively stable through life [34] and social inequalities in physical activity have been found as early as

Table 6
Model fit and parameter estimates for structural equation models of social class at birth and at ages 5, 10, 30, and 34 years and physical activity during transports at age 34 years for men ($n = 4605$) and women ($n = 5019$) in the 1970 British birth cohort

	Model 1		Model 2		Model 3	
	Accumulation of risk (additive effects)		Accumulation of risk (trigger effect)		Critical period	
	Men	Women	Men	Women	Men	Women
Fit indices						
AIC	292045	303563	293413	304312	293936	304707
BIC	292392	303915	293645	304546	294219	304994
Parameter estimates						
Social class on social class at the subsequent period						
SC34 SC30	0.481	0.559*	0.468*	0.545*	0.672*	0.695*
SC30 SC10	0.193	0.209*	0.331*	0.277*	0.346*	0.283*
SC10 SC5	0.629	0.649*	0.655*	0.660*	0.625*	0.648*
SC5 SC0	0.443	0.446*	0.477*	0.465*	0.443*	0.448*
Social class on physical activity during transports at age 34 y						
PA SC34	0.067	0.090	0.040	0.189*	—	—
PA SC30	−0.072	0.054	—	—	—	—
PA SC10	0.060	0.131*	—	—	0.058	0.148*
PA SC5	−0.010	0.022	—	—	−0.017	0.030
PA SC0	−0.018	0.072*	—	—	−0.018	0.080*

PA = physical activity; SC = social class.
* $P < .05$ (two tailed).

adolescence [35], perhaps social class during childhood would have associated more strongly with physical activity during adulthood had this variable been measured. Physical activity at home was not measured, so we could not provide a full picture of the association between social class across the life course and physical activity during adulthood in all domains of life, and we could not fully adjust our analyses for physical activity in every other domain. Finally, this was an observational study, from which causality cannot be inferred.

Conclusions

The accumulation of risk model with additive effects fit the data best for all three outcomes of physical activity we studied (physical activity during leisure time, at work, and during transports). In this model, and in our sample, social class at birth and at ages 0, 5, 10, 30, and 34 years were associated with physical activity during adulthood additively and independently of social class later in life, although the magnitude and direction of the associations varied by physical activity outcome and by sex. Structural equation modeling appears to be a helpful tool in selecting among competing models in life course epidemiology.

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Appendix. Online resource 1—physical activity scores

Physical activity score for leisure-time physical activity

Subjects were shown a list of common leisure-time physical activities (see card in the following). They were then asked: "Do you regularly take part in any of the activities on this card. By regularly I mean at least once a month, for most of the year?" Answers were: "yes" or "no". Subjects who answered "yes" were then asked: "How often do you take part in any activity of this type?" Answers were: "everyday," "4 to 5 days a week", "2 to 3 days a week", "once a week", "2 to 3 times a month", or "less often." They were also asked: "And when you take part in any activity of this type, would you say you got out of breath or sweaty?" Answers were "most times," "sometimes," "rarely," or "never." A physical activity score representing 8 weeks of habitual physical activity was computed based on these answers. Subjects who did not exercise were given a value of zero. The score for those who exercised was computed by multiplying how often they did so (frequency, >8 weeks) by how often they got out of breath or sweaty (intensity). For frequency, subjects who exercised "everyday" were given a value of 56 (8 weeks multiplied by 7 days a week). Those who exercised "4 to 5 days a week" were given a value of 36 (8 weeks multiplied by 4.5 days a week). Those who exercised 2 to 3 days a week were given a value of 20 (8 weeks multiplied by 2.5 days a week). Those who exercised once a week were given a value of 8 (8 weeks multiplied by 1 day a week). Those who exercised 2 to 3 times a month were given a value of 5 (2.5 days a month multiplied by 2 months [8 weeks was considered 2 months; this was necessary to obtain only integer values and treat this outcome as a count variable in the models]). Finally, those who exercised "less often" were considered to be exercising once every 4 weeks and were given a value of 2 (8 weeks multiplied by 1 day every 4 weeks). Next, for intensity, all subjects who got out of breath or sweaty "most times" were given a value of 4. Those who got out of breath or sweaty "sometimes" were given a value of 3. Those who got out of breath or sweaty "rarely" were given a value of 2. Finally, those who got out of breath or sweaty "never" were given a value of 1. These two sets of values were multiplied to compute the subjects' physical activity score. The score took 23 values between 0 (no exercise at all) and 224 (subject exercises "everyday" and gets out of breath or sweaty "most times"). This score approximated energy expenditure: the higher the score, the more physically active the subjects were and the more energy they expended through physical activities. The score was not normally distributed, having a range from 0 to 224 with a median of 40 and mode of 0. The score was positively skewed (skewness = 1.103; standard error = 0.025; Kolmogorov–Smirnov test of normality with Lilliefors Significance Correction $P < .001$). The physical activity score was used at the dependent variable for leisure-time physical activity, and zero-inflated Poisson models were used to account for the large number of zeros and positive skewness.

Exercise

Card NN

1. Take part in competitive sport of any kind
2. Go to "keep fit" or aerobics classes
3. Go running or jogging
4. Go swimming
5. Go cycling
6. Go for walks
7. Take part in water sports
8. Take part in outdoor sports
9. Go dancing
10. Take part in any other sport or leisure activity which involves physical exercise

Source: National Centre for Social Research (2004). 1970 British Cohort Study—2004 Survey

Appendix A, Fieldwork Documents, p. 136. Available at: http://www.cls.ioe.ac.uk/core/documents/download.asp?id=877&log_stat=1.

Physical activity score for physical activity at work

Subjects were asked: "Do you use a computer at work?" Answers were: "yes" or "no." Subjects who answered "Yes" were then asked: "How often do you use the computer?" Answers were: "Daily," "2 to 4 times a week," "once a week," or "less than once a week." A score for physical activity at work over 8 weeks was computed based on these answers. Subjects who said they did not use a computer at work were given a value of zero. Subjects who said they used a computer at work were given a value based on how often they said they used it in a week. Subjects who used a computer daily were given a value of 56 (8 weeks multiplied by 7 days a week). Subjects who used a computer 2 to 4 times a week were given a value of 24 (8 weeks multiplied by 3 days a week, the average of 2 and 4). Subjects who used a computer once a week were given a value of 8 (8 weeks multiplied by 1 day a week). Subjects who used a computer "less than once a week" were considered to be using a computer once every 4 weeks. They were given a value of 2 (8 weeks multiplied by 1 day every 4 weeks). The score for physical activity at work took 5 values between 0 and 56. The higher the score, the more subjects were using a computer at work, indicating less physical activity at work. To facilitate analysis and interpretation, the score was reverse coded, so that the higher the score, the less subjects were using a computer a work, indicating more physical activity at work (higher score, more physical activity at work). The (reverse coded) score could be interpreted as "how many days the participant does not use a computer at work over 8 weeks." The (reverse coded) score was not normally distributed, having a range from 0 to 56 with a median and a mode of 0. The (reverse coded) score was positively skewed (skewness = 0.634; SE = 0.027; Kolmogorov–Smirnov test of normality with Lilliefors Significance Correction $P < .001$). This score was used at the dependent variable for physical activity at work, and zero-inflated Poisson models were used to account for the large number of zeros and positive skewness.

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Brief Original Report

Trends in leisure-, transport-, and work-related physical activity in Canada 1994–2005

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A B S T R A C T

Background. In Canada, data show adults had a lower energy intake in 2004 than in 1972. Data also show adults expended more energy through leisure-time physical activity in 2000 than in 1981. On the other hand, the prevalence of overweight and obesity (combined) rose from 49.2% to 59.1% between 1978 and 2004.

Purpose. This study aimed to chart trends in leisure-, transport-, and work-related physical activity in Canada between 1994 and 2005.

Methods. We used nationally representative data from the three National Population Health Surveys (1994, 1996, and 1998) and the three Canadian Community Health Surveys (2000, 2003, and 2005) (a repeated cross-sectional design). Sample sizes ranged from $n=17\,626$ (in 1994) to $n=132\,221$ (in 2005).

Results. Between 1994 and 2005, men became less inactive during leisure time (−9.94% [9.89%–9.98%]), less inactive during transports (−15.31% [15.26%–15.35%]), and more inactive at work (+5.18% [5.14%–5.22%]). Similar results were found for women.

Conclusions. Declining levels of physical activity at work may help explain the rising prevalence of overweight and obesity in Canada.

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Introduction

In 2004, Canadian adults had a lower energy intake than in 1972 (Garriguet, 2004). As well, in 2000, Canadian adults expended more energy through leisure-time physical activity than in 1981 (Craig et al., 2004). Nonetheless, the prevalence of overweight and obesity (combined) among Canadian adults rose from 49.2% to 59.1% between 1978 and 2004 (Tjepkema, 2005). Since a positive energy balance is required for weight gain to occur, we hypothesized that Canadians may have become more inactive during transports or at work. Indeed, declining levels of physical activity during transports or at work and the accompanying decline in energy expenditure at the population level may have tipped the scale toward a positive energy balance, thus helping to explain the rising prevalence of overweight and obesity in Canada. This study aimed to chart trends in leisure-, transport, and work-related physical activity in Canada between 1994 and 2005.

Methods

In a repeated cross-sectional design, we analyzed data from six nationally representative health surveys. These were the National Population Health Surveys (1994, 1996, and 1998–1999) and the Canadian Community Health Surveys (2000–2001, 2003, and 2005) (Statistics Canada, 1996–2006). Sample sizes ranged from $n=17\,626$ (in 1994) to $n=132\,221$ (in 2005). Surveys were representative of roughly 98% of the population aged ≥12 years. Statistics Canada's sample weights were used throughout.

Our independent variable was the survey year (1994, 1996, 1999, 2001, 2003, or 2005). Our three dependent variables were leisure time, transport-, and work-related physical activity. For leisure-time physical activity, in each survey, a list of physical activities is provided to participants, who indicate how many times they performed each activity over the past three months and the average duration of each bout. Participant's daily energy expenditure (in $\text{kcal} \cdot \text{kg}^{-1} \cdot \text{day}^{-1}$) is then computed, as detailed in Katzmarzyk and Tremblay (2007). Participants who expended less than 1.5 $\text{kcal} \cdot \text{kg}^{-1} \cdot \text{day}^{-1}$ were considered inactive during leisure time. For transport-related physical activity, participants answered the question: “In a typical week in the past 3 months, how many hours did you usually spend walking to work or to school or while doing errands?” Choices were: “None”, “Less than 1 h”, “From 1 to 5 h”, “From 6 to 10 h”, “From 11 to 20 h”, or “More than 20 h.” Participants who answered “None” were considered inactive during transports. For work-related physical activity, participants answered the question: “Thinking back over the past 3 months, which of the following best describes your usual daily activities or work habits?” Choices were: “Usually sit during the day and don't

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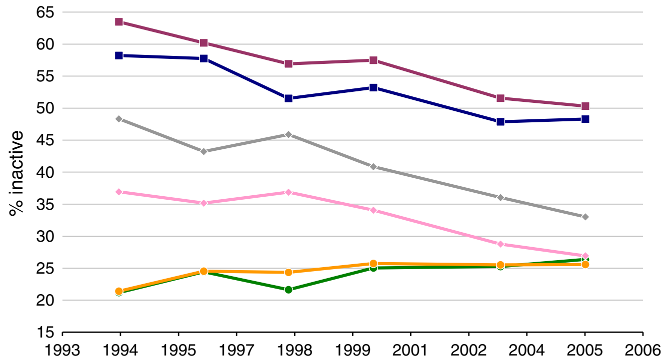

Fig. 1. Trends in leisure-, transport-, and work-related physical inactivity in Canada 1994-2005. This figure illustrates a significant downward trend for inactivity during leisure time and transports for men ($p<0.001$) and women ($p<0.001$) and a significant upward trend for inactivity at work for men ($p<0.001$) and women ($p<0.001$). Trends for men are shown in blue (leisure), gray (transport), and green (work). Trends for women are shown in red (leisure), pink (transport), and orange (work).

walk around very much", "Stand or walk quite a lot during the day but don't have to carry or lift things very often", "Usually lift or carry light loads, or have to climb stairs or hills often", or "Do heavy work or carry very heavy loads." Participants who answered: "Usually sit during the day and don't walk around very much" were considered inactive at work. Confounders were age (in 5-year increments) and education ("Less than secondary", "Secondary graduate", "Other post-secondary", or "Post-secondary graduate").

Plots, statistical testing, and confidence intervals were produced through SPSS 15.0 (SPSS, Chicago, IL) and Excel 2002 (Microsoft, Redmond, WA). Three logistic regressions were performed to test for temporal trends, with leisure-, transport-, or work-related physical activity entered as the dependent variable and the survey year, age, and education entered as independent variables. Confidence intervals for the proportions of physically inactive individuals and the difference between them were computed using the Wilson method without continuity correction (Newcombe, 1998). Analyses were restricted to men and women aged 20 to 65 years.

Results

There was a significant downward trend for inactivity during leisure time and transports for men ($p<0.001$) and women ($p<0.001$) (Fig. 1). Conversely, there was a significant upward trend for inactivity at work for men ($p<0.001$) and women ($p<0.001$) (Fig. 1). Between 1994 and 2005, men became less inactive during leisure time (−9.94% [9.89%–9.98%]), less inactive during transports (−15.31% [15.26%–15.35%]), and more inactive at work (+5.18% [5.14%–5.22%]) (Table 1). Similar results were found for women. Between 1994 and 2005, women became less inactive during leisure time (−13.17% [13.13%–13.22%]), less inactive during transports (−9.99% [9.95%–10.04%]), and more inactive at work (+4.18 [4.14–4.22]) (Table 1).

Discussion

This study's objective was to chart trends in leisure-, transport-, and work-related physical activity in Canada between 1994 and 2005. Our hypothesis was that Canadians may have become more inactive during transports or at work. Results show that Canadian adults have become less inactive during leisure time and transports and more inactive at work. Our hypothesis was thus only partially verified.

Traditionally, physical activity guidelines and promotion have focused on leisure-time physical activity. Our results, which replicate those found by Craig et al. (2004), support the notion that those promoting leisure-time physical activity in Canada have had some success. However, this increase in leisure-time physical activity appears not to have been sufficient to curb the overweight and obesity epidemic (Tjepkema, 2005). This finding, combined with ours and with the fact that Canadian adults had a lower energy intake in 2004 than in 1972 (Garriguet, 2004), may encourage public health authorities to turn their attention to other domains of physical activity, especially physical activity at work.

Similar trends have been found in England (Stamatakis et al., 2007), Finland (Barengo et al., 2002), the U.S. (Brownson et al., 2005), Spain (Román-Viñas et al., 2007), and China (Monda et al., 2008). In all countries but China (data not available), leisure-time physical activity has increased. In England, physical activity during transports has increased, whereas in Finland, the U.S., and Spain, it has decreased. In all countries, physical activity at work has decreased.

The main strength of this study is that it looked at three domains of physical activity (leisure, transport, and work) in large, nationally representative samples. While it may be encouraging to report that physical activity levels are rising by looking at leisure-time physical activity only (Craig et al., 2004), time use studies have shown that leisure time accounts for only about 21% of adult's total time (Aguiar and Hurst, 2007). It also has been suggested that leisure-time physical activity accounts for only a small portion (about 100 kcal • day^{-1}) of the energy adults expend daily in physical activities, with non-exercise activity thermogenesis (such as physical activity at work) accounting for most of the expenditure (Levine, 2007). Therefore, we feel that a more accurate description of trends in physical activity levels is obtained by monitoring leisure-, transport-, and work-related physical activity.

This study's main limitation is that it is based on self-reports of physical activity involvement. Self-reports have been shown to overestimate leisure-time physical activity (Troiano et al., 2008). Another limitation is the rather crude measurement of transport-and work-related physical activity, which were both assessed using a single question. A third limitation regarding the statistical analysis is our use of sample weights that did take into account the sample design of each survey, but that did not take into account the complex (multi-survey) nature of the design. As our results are all highly significant ($p<0.001$), they would most likely have remained so at the

Table 1
Proportion of Canadian adults physically inactive during leisure, transports, and at work in Canada, 1994–2005 % inactive.

	Leisure*		Transport*		Work**	
	Men	Women	Men	Women	Men	Women
1994	58.22 (58.19–58.25)	63.48 (63.45–63.51)	48.32 (48.29–48.35)	36.92 (36.89–36.95)	21.18 (21.15–21.21)	21.39 (21.36–21.42)
1996	57.75 (57.72–57.78)	60.19 (60.16–60.22)	43.22 (43.19–43.25)	35.16 (35.13–35.19)	24.42 (24.39–24.45)	24.52 (24.49–24.55)
1999	51.51 (51.48–51.54)	56.91 (56.88–56.94)	45.88 (45.85–45.91)	36.86 (36.83–36.89)	21.63 (21.60–21.66)	24.34 (24.31–24.37)
2001	53.21 (53.18–53.24)	57.47 (57.44–57.50)	40.85 (40.82–40.88)	34.05 (34.02–34.08)	25.02 (24.99–25.05)	25.73 (25.70–25.76)
2003	47.86 (47.83–47.89)	51.54 (51.51–51.57)	36.03 (36.00–36.06)	28.76 (28.73–28.79)	25.25 (25.22–25.28)	25.51 (25.48–25.54)
2005	48.28 (48.25–48.31)	50.30 (50.27–50.33)	33.01 (32.98–33.04)	26.92 (26.89–26.95)	26.36 (26.33–26.39)	25.57 (25.54–25.60)
2005–1994	−9.94 (9.89–9.98)	−13.17 (13.13–13.22)	−15.31 (15.26–15.35)	−9.99 (9.95–10.04)	+5.18 (5.14–5.22)	+4.18 (4.14–4.22)

* Downward trend significant for men ($p<0.001$) and women ($p<0.001$).
** Upward trend significant for men ($p<0.001$) and women ($p<0.001$).

$p<0.05$ level if the complex nature of the design had been taken into account in the variance estimates.

Conclusion

Between 1994 and 2005, Canadian adults have become less inactive during leisure time and transports and more inactive at work. Since most Canadians spend the majority of weekdays at work, declining levels of physical activity at work may help explain the rising prevalence of overweight and obesity in Canada.

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Conflict of interest statement

We declare no conflict of interest.

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